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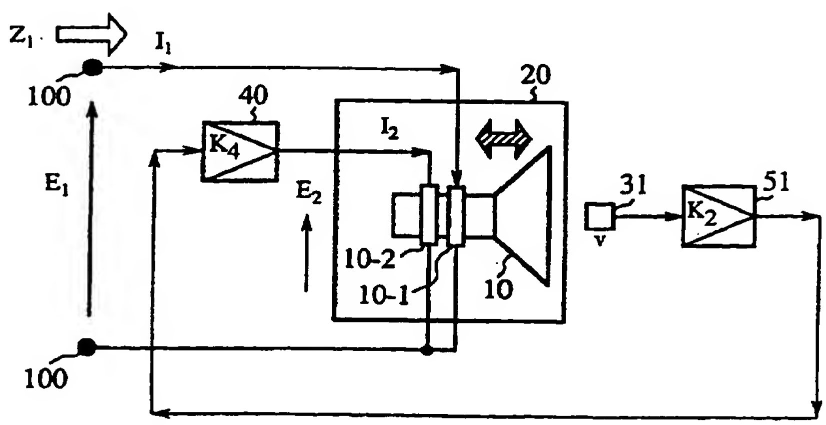
(54) Abstract Title
Second voice coil in MFB loudspeaker receives feedback signal

(57) An acoustic signal is input to a first voice coil 10-1. A sensor 31 detects the vibration of the loudspeaker and returns a feedback signal to amplifier 40. The amplifier amplifies the feedback signal and applies it to the second voice coil 10-2.

The sensor may detect either displacement or velocity or acceleration and many embodiments are described in which the feedback signal is composed of the sum of the signals from a displacement sensor and/or a velocity sensor and/or an acceleration sensor.

Further embodiments are described in which integration and differentiation are used to derive the displacement, velocity and acceleration signals.

FIG.3



GB 2 342 001 A

FIG.1
(PRIOR ART)

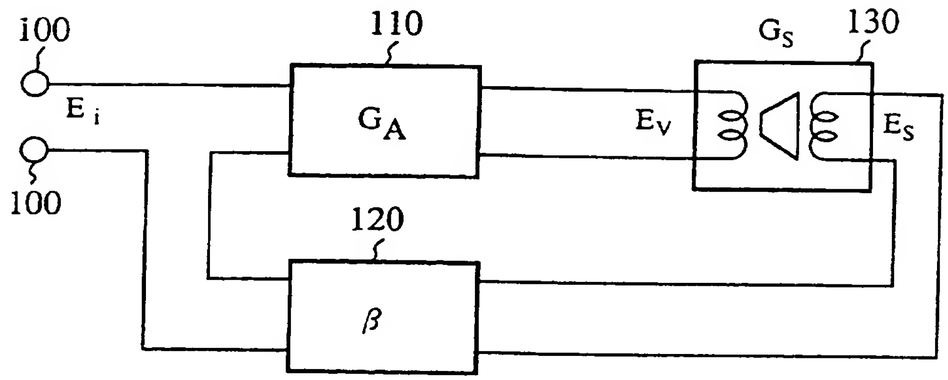


FIG.3

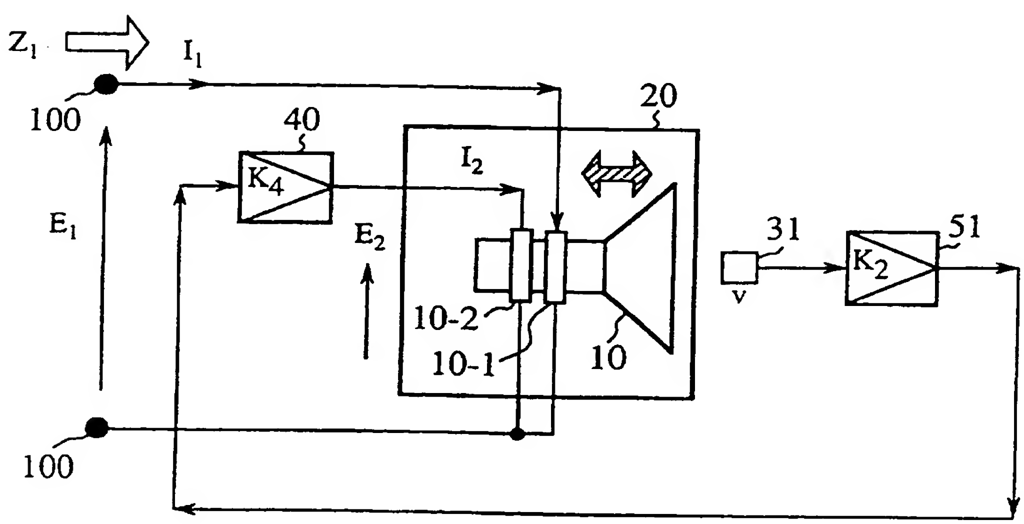


FIG.2A (PRIOR ART)

VELOCITY MFB

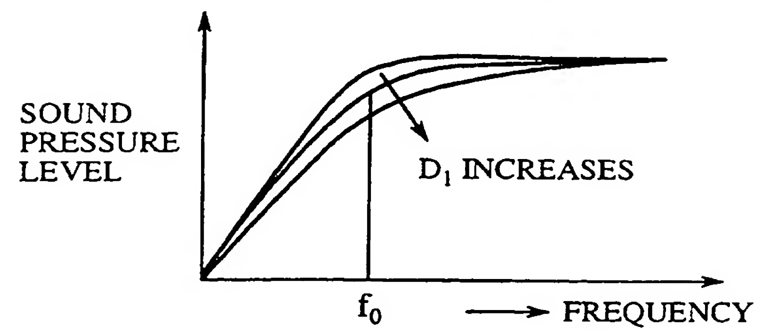


FIG.2B (PRIOR ART)

ACCELERATION MFB

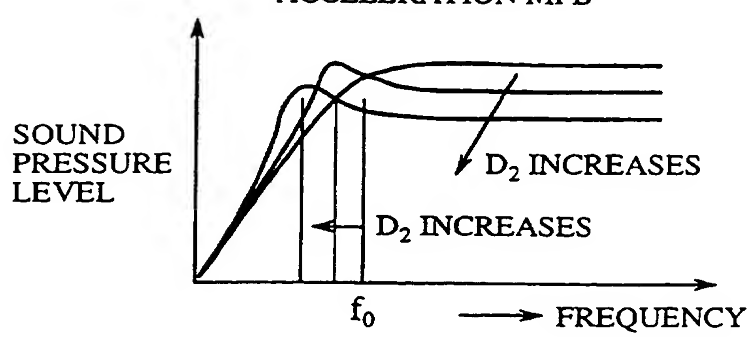


FIG.2C (PRIOR ART)

DISPLACEMENT MFB

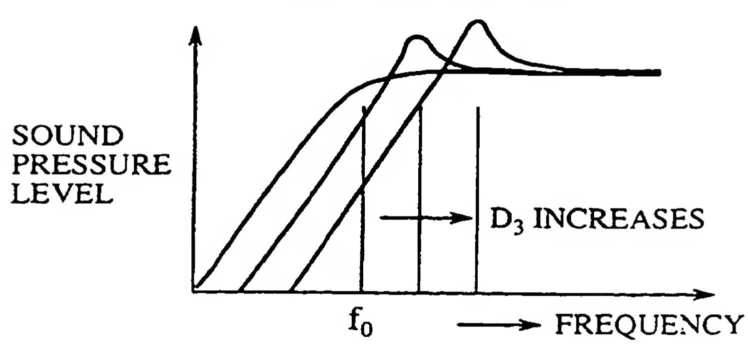


FIG.4

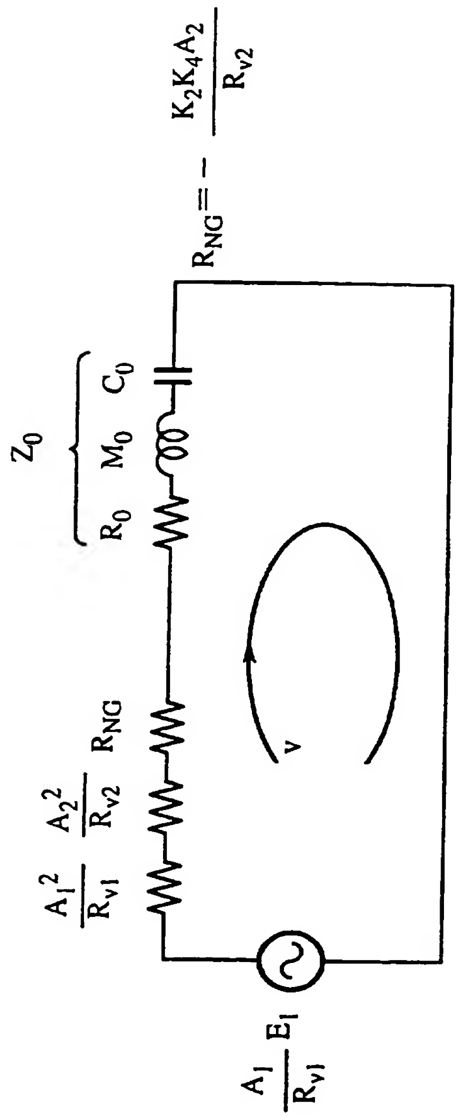

$R_{NG} = -\frac{K_2 K_4 A_2}{R_{v2}}$
Z_0
R_0
M_0
C_0
$\frac{A_1^2}{R_{v1}}$
$\frac{A_2^2}{R_{v2}}$
R_{NG}
v
$\frac{A_1}{R_{v1}} E_1$

FIG.5

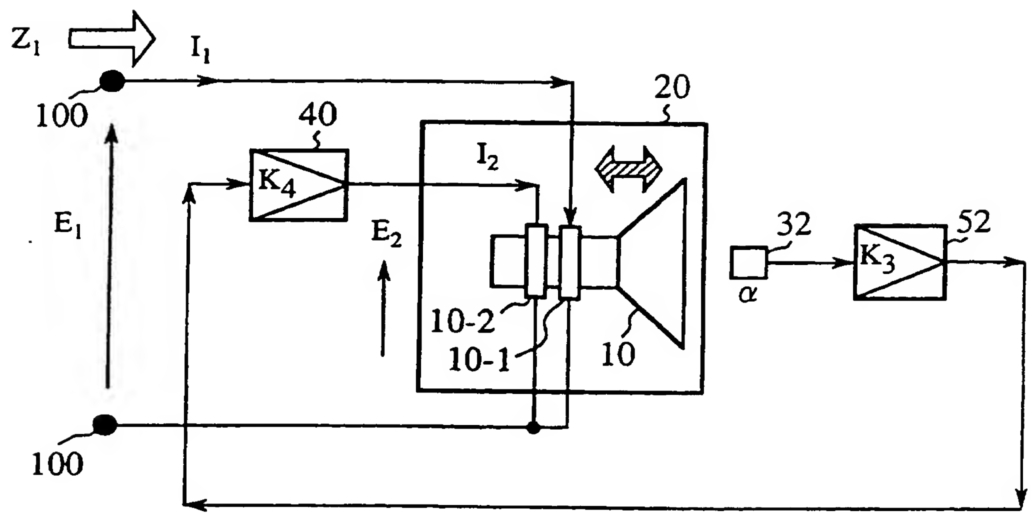

Z1
I1
100
20
40
I2
K4
E1
E2
32
52
K3
α
10-2
10-1
10
100

FIG.7

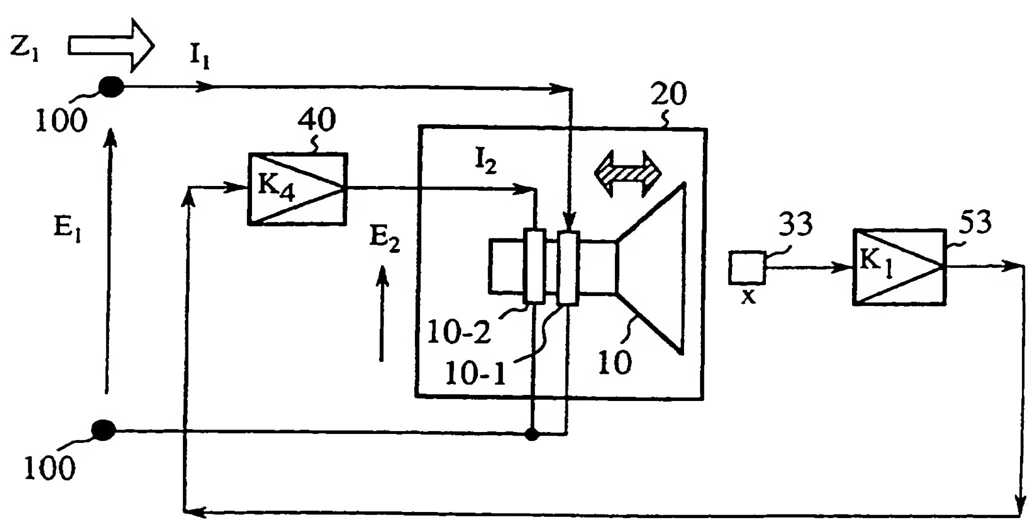

Z1
I1
100
20
40
I2
K4
E1
E2
33
53
K1
x
10-2
10-1
10
100

FIG.6

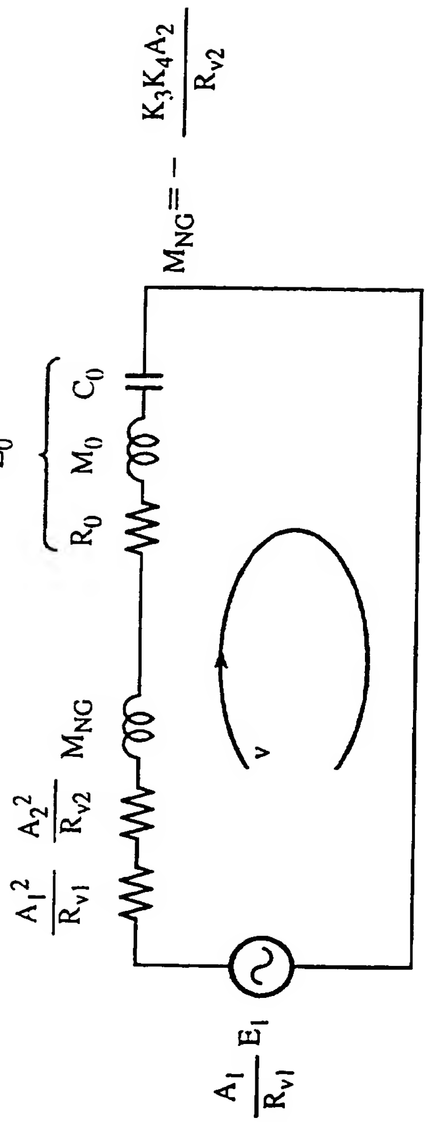
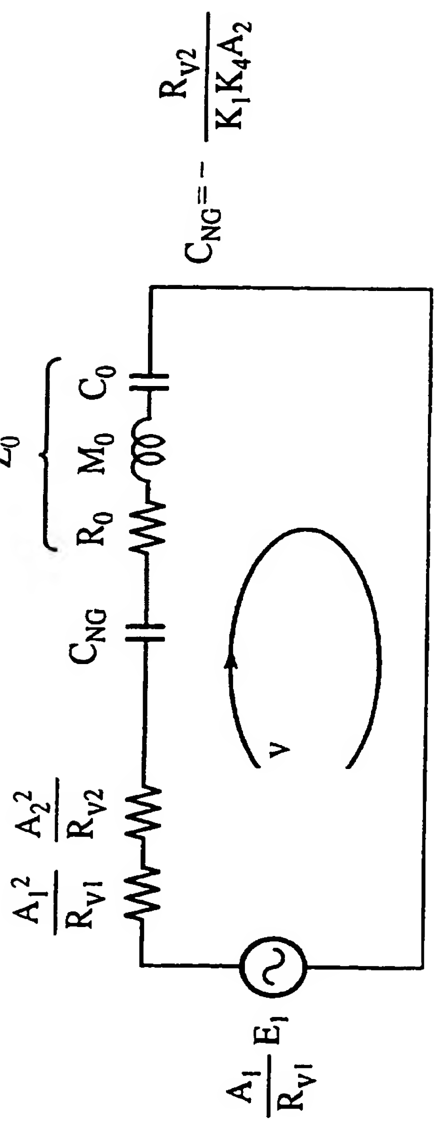

$M_{NG} = -\frac{K_3 K_4 A_2}{R_{v2}}$
Z_0
R_0
M_0
C_0
M_{NG}
$\frac{A_2^2}{R_{v2}}$
$\frac{A_1^2}{R_{v1}}$
v
$\frac{A_1}{R_{v1}} E_1$

FIG.8



Z_0
R_0
M_0
C_0
C_{NG}
$\frac{A_1^2}{R_{V1}}$
$\frac{A_2^2}{R_{V2}}$
$\frac{A_1}{R_{V1}}E_1$
v
$C_{NG} = -\frac{R_{V2}}{K_1 K_4 A_2}$

FIG.9

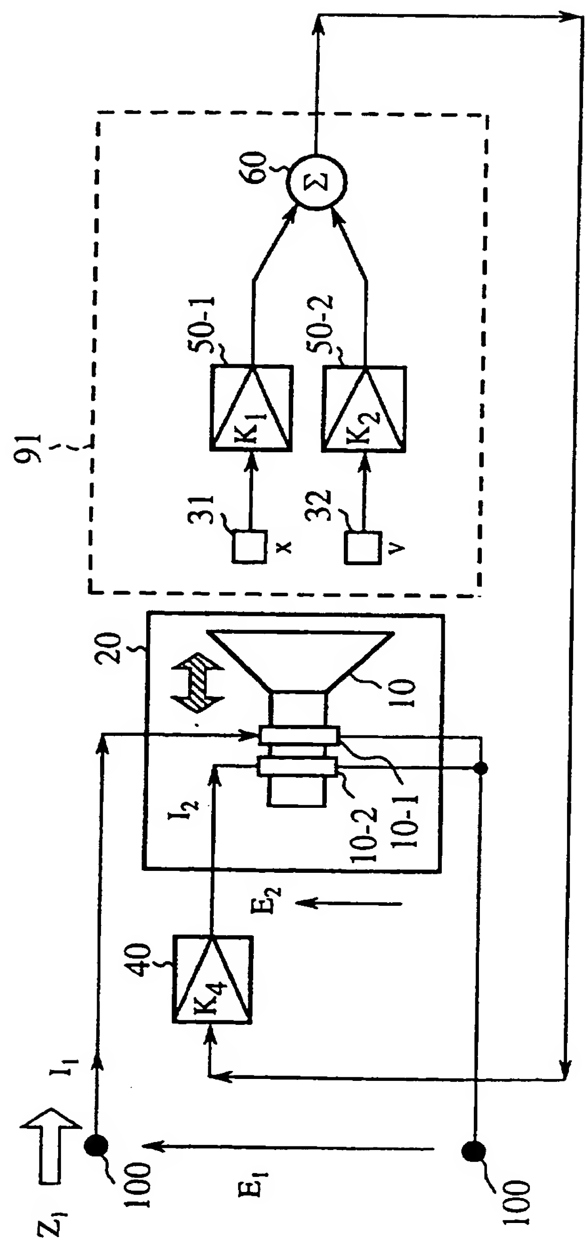
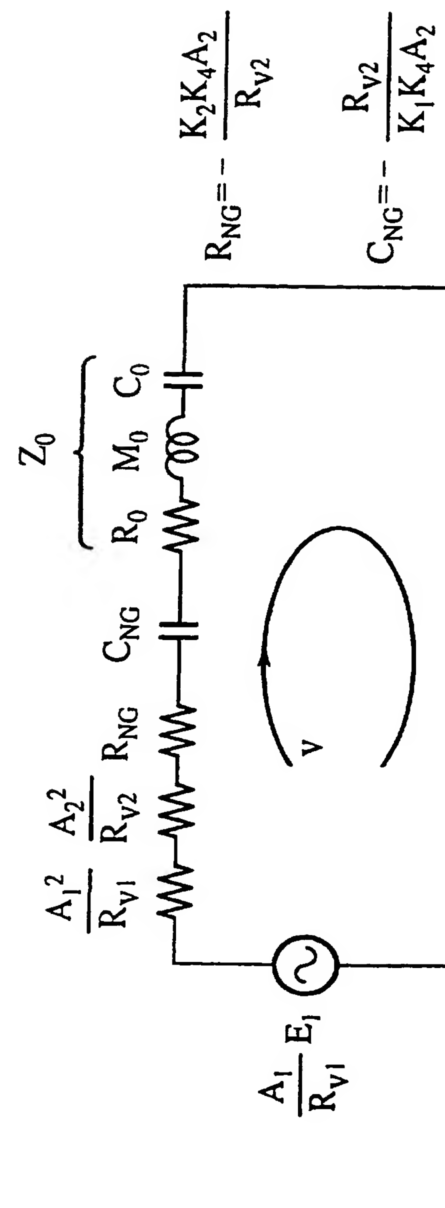
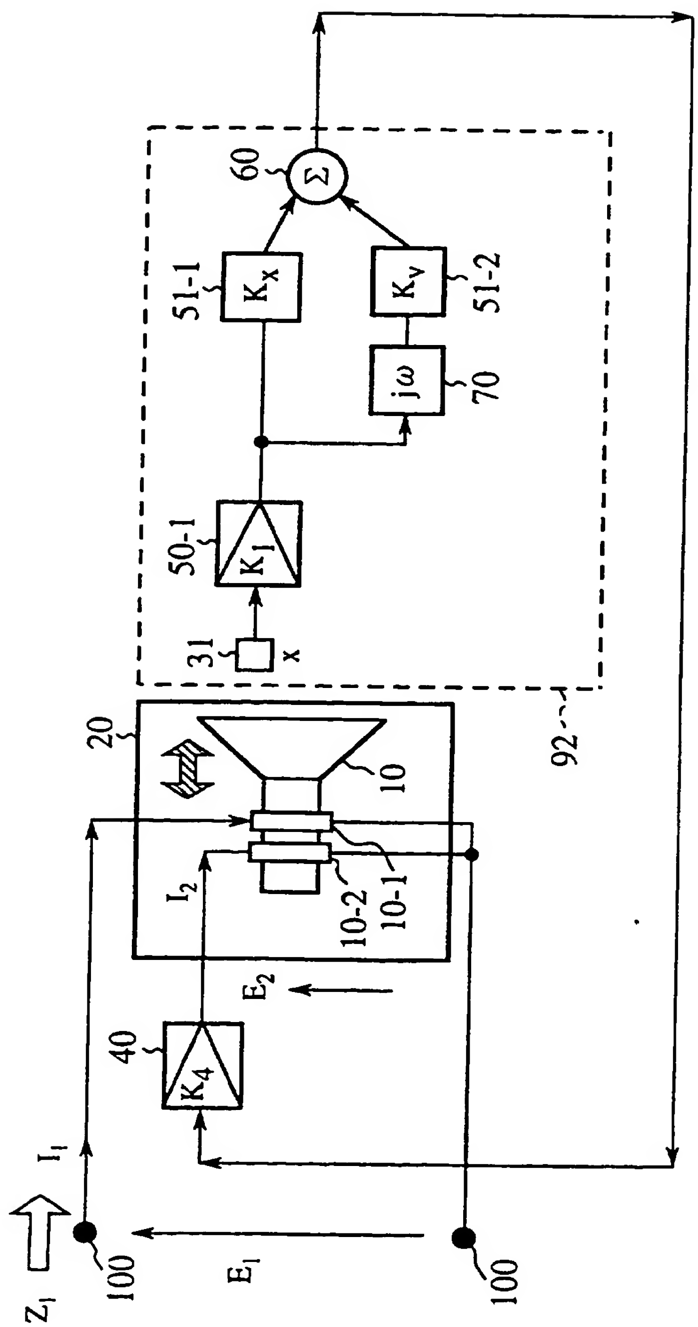

91
31
x
32
v
K1
K2
50-1
50-2
60
Σ
20
10
10-1
10-2
I2
E2
40
K4
I1
Z1
100
E1
100

FIG.10



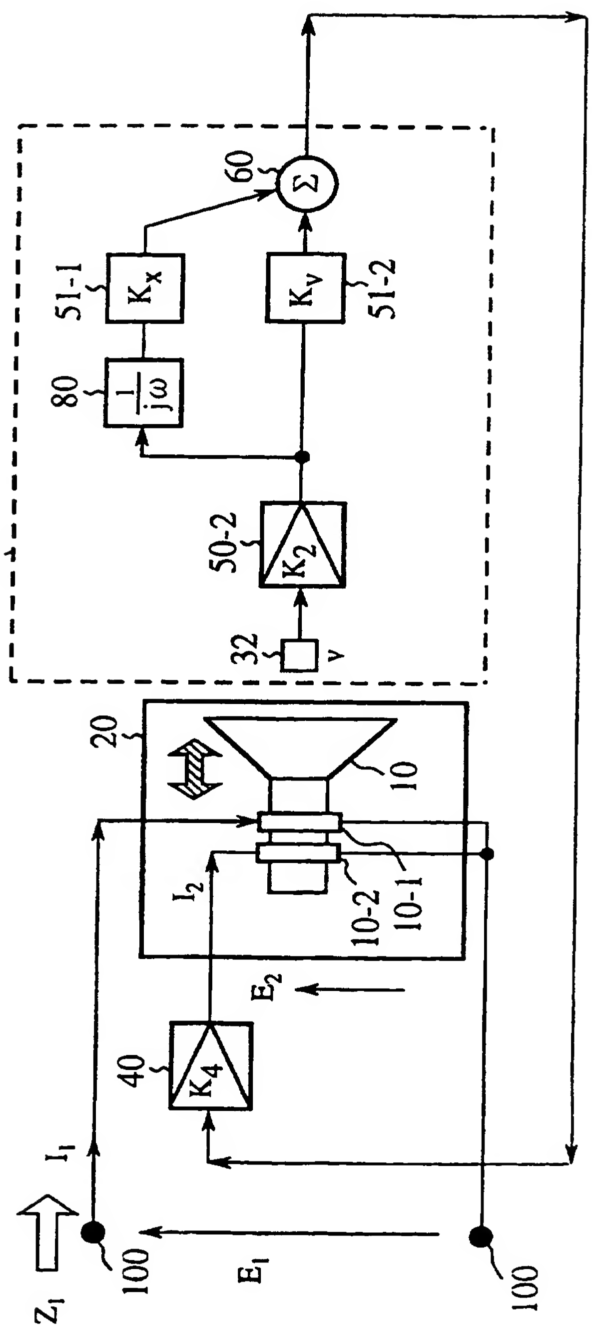
$\frac{A_1}{R_{V1}}E_1$
$\frac{A_1^2}{R_{V1}}$
$\frac{A_2^2}{R_{V2}}$
R_{NG}
C_{NG}
R_0
M_0
C_0
Z_0
v
$R_{NG}= - \frac{K_2K_4A_2}{R_{V2}}$
$C_{NG}= - \frac{R_{V2}}{K_1K_4A_2}$

FIG.11



20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100
31
x
50-1
K_1
$j\omega$
70
51-1
K_x
K_v
51-2
60
Σ
92

FIG.12



93
80
$\frac{1}{j\omega}$
51-1
K_x
60
Σ
K_v
51-2
50-2
K_2
32
v
20
10
10-2
10-1
I_2
40
K_4
E_2
I_1
Z_1
100
E_1
100

FIG.13

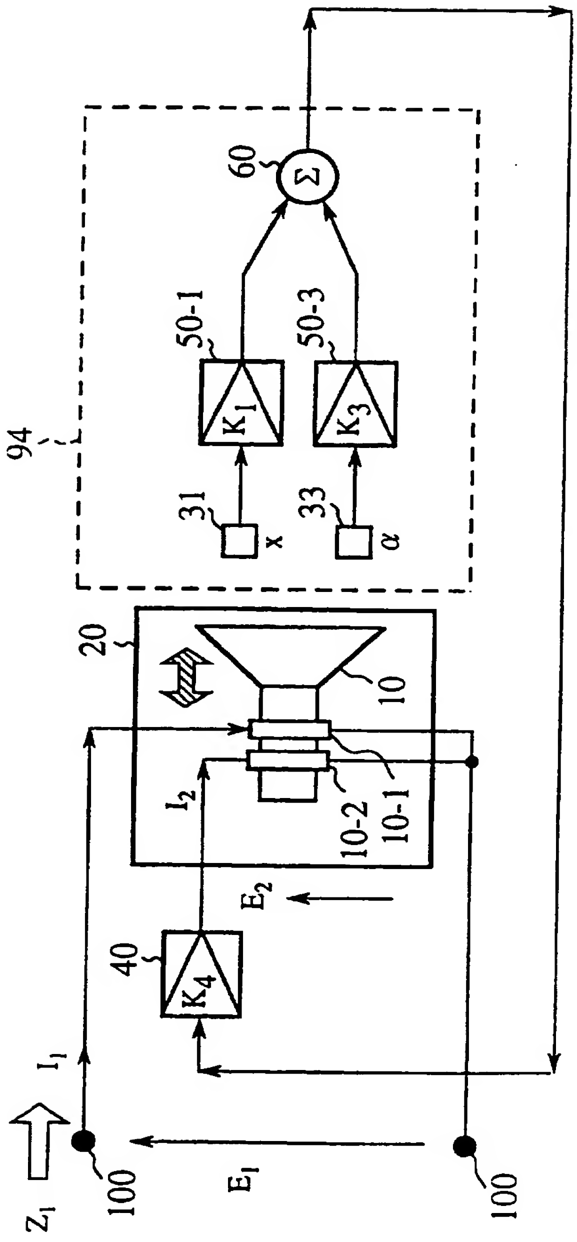
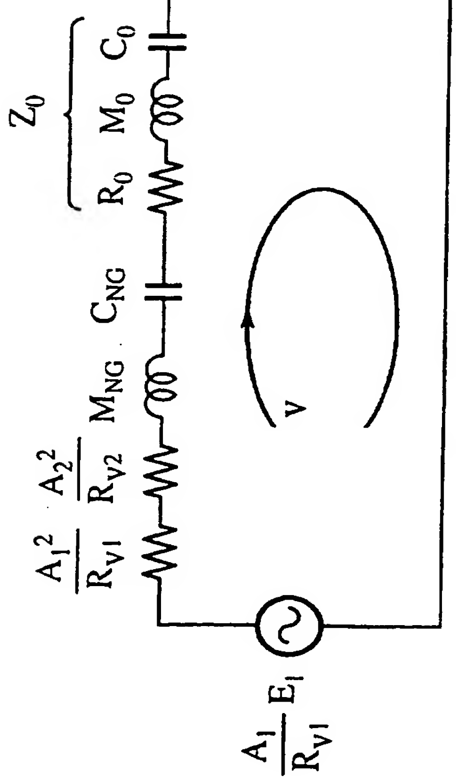

94
31
x
33
α
50-1
K1
50-3
K3
60
Σ
20
10
10-1
10-2
I2
E2
40
K4
I1
Z1
100
E1
100

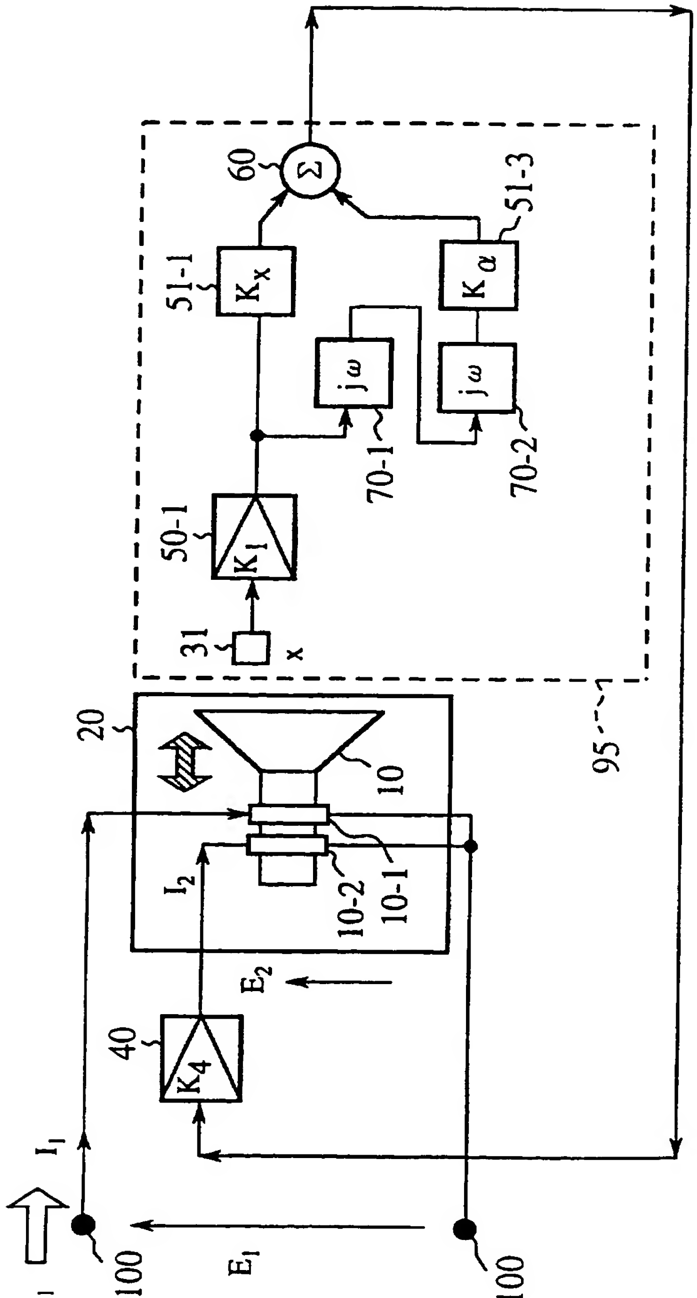
FIG.14



$$M_{NG} = -\frac{K_3 K_4 A_2}{R_{V2}}$$

$$C_{NG} = -\frac{R_{V2}}{K_1 K_4 A_2}$$

FIG.15



60
Σ
51-1
K_x
51-3
K_α
$j\omega$
$j\omega$
70-1
70-2
50-1
K_1
31
x
20
10
10-2
10-1
95
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100

FIG.16

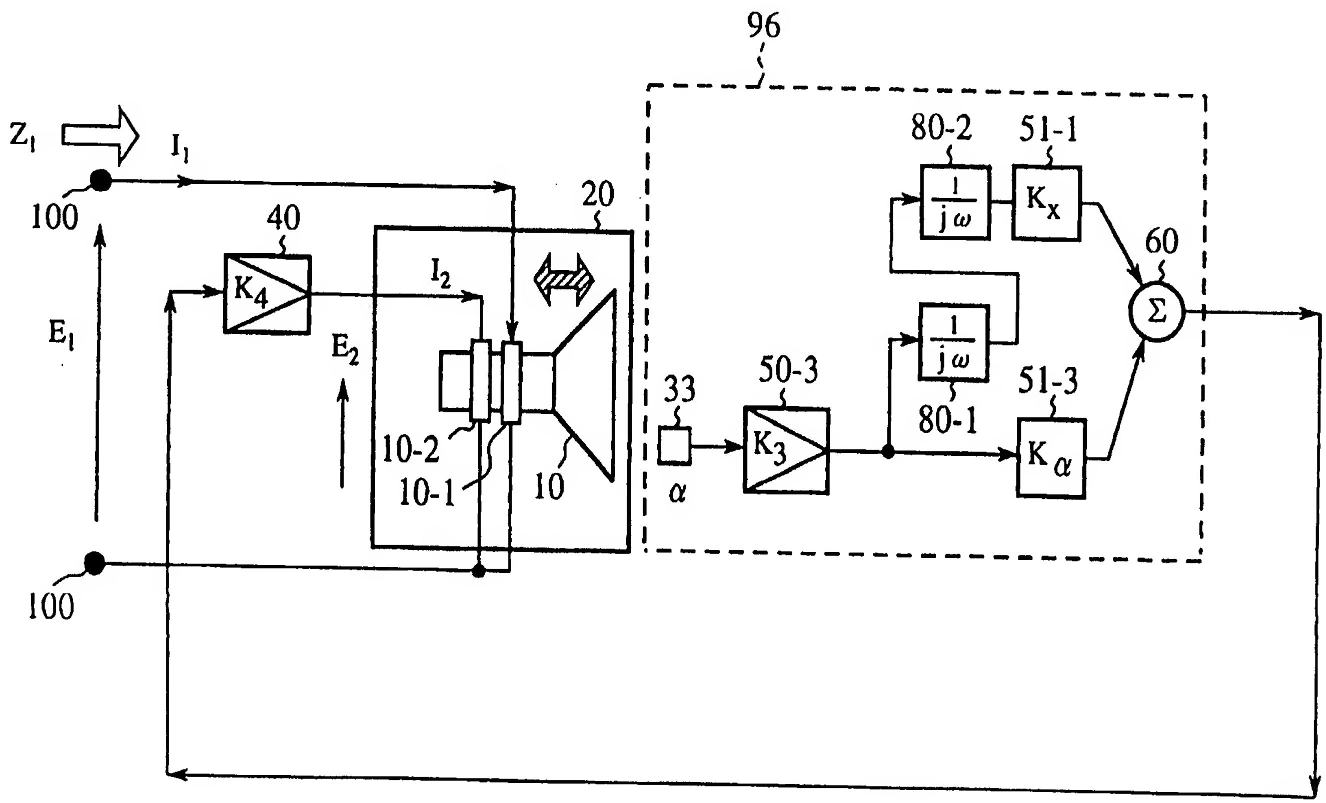
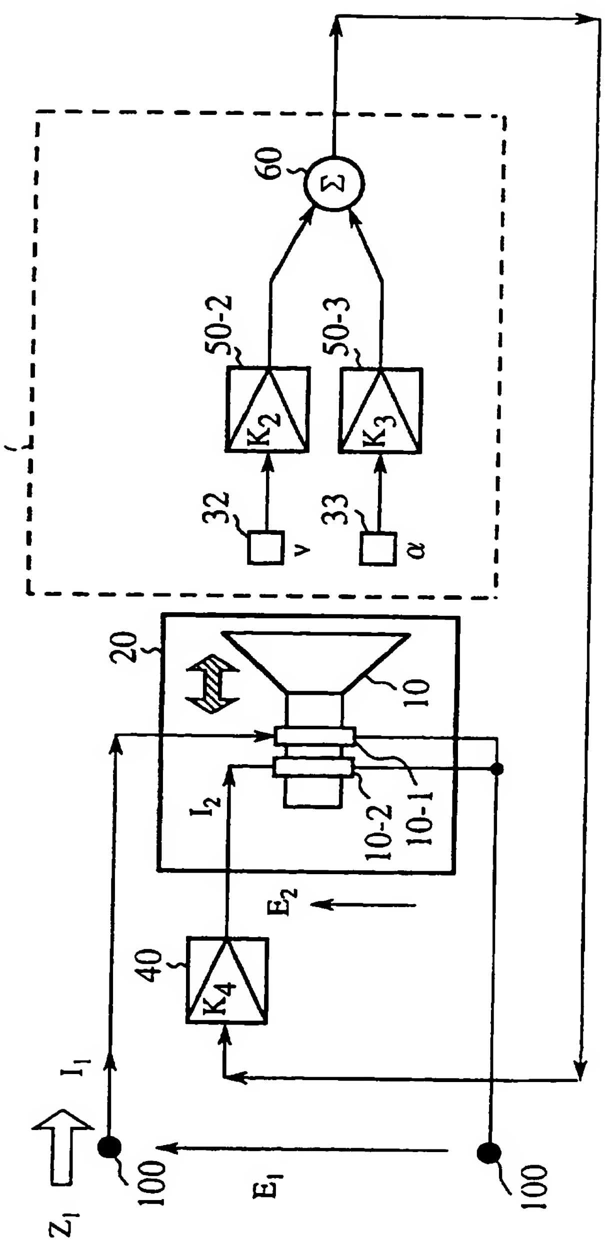
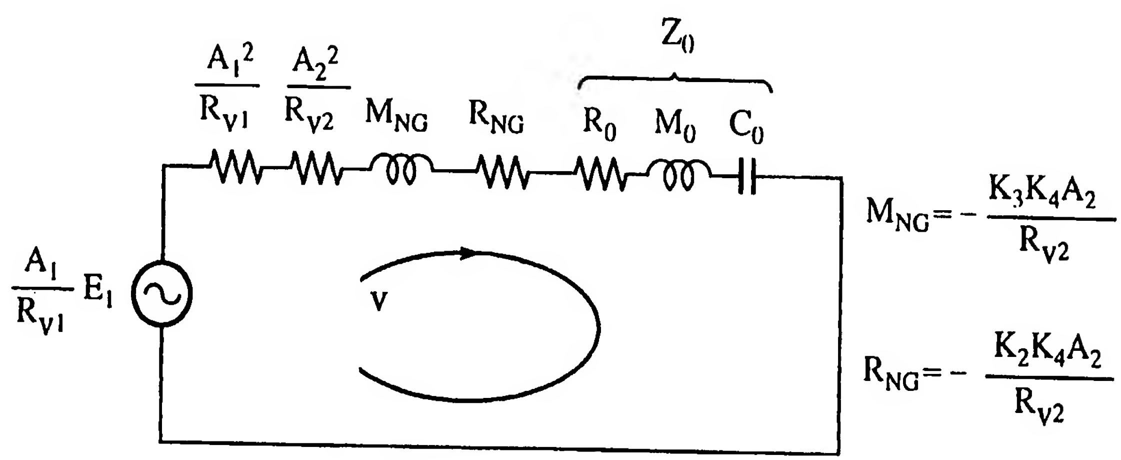

Z1
I1
100
40
K4
20
I2
E1
E2
10-2
10-1
10
100
96
33
α
50-3
K3
80-2
1/jω
51-1
Kx
80-1
51-3
Kα
60
Σ

FIG.17



97
32
v
33
α
K2
K3
50-2
50-3
60
Σ
20
10
10-1
10-2
I2
I1
E2
E1
40
K4
100
100
Z1

FIG.18



$\frac{A_1}{R_{V1}} E_1$
$\frac{A_1^2}{R_{V1}}$
$\frac{A_2^2}{R_{V2}}$
M_{NG}
R_{NG}
Z_0
R_0
M_0
C_0
v
$M_{NG} = -\frac{K_3 K_4 A_2}{R_{V2}}$
$R_{NG} = -\frac{K_2 K_4 A_2}{R_{V2}}$

FIG.19

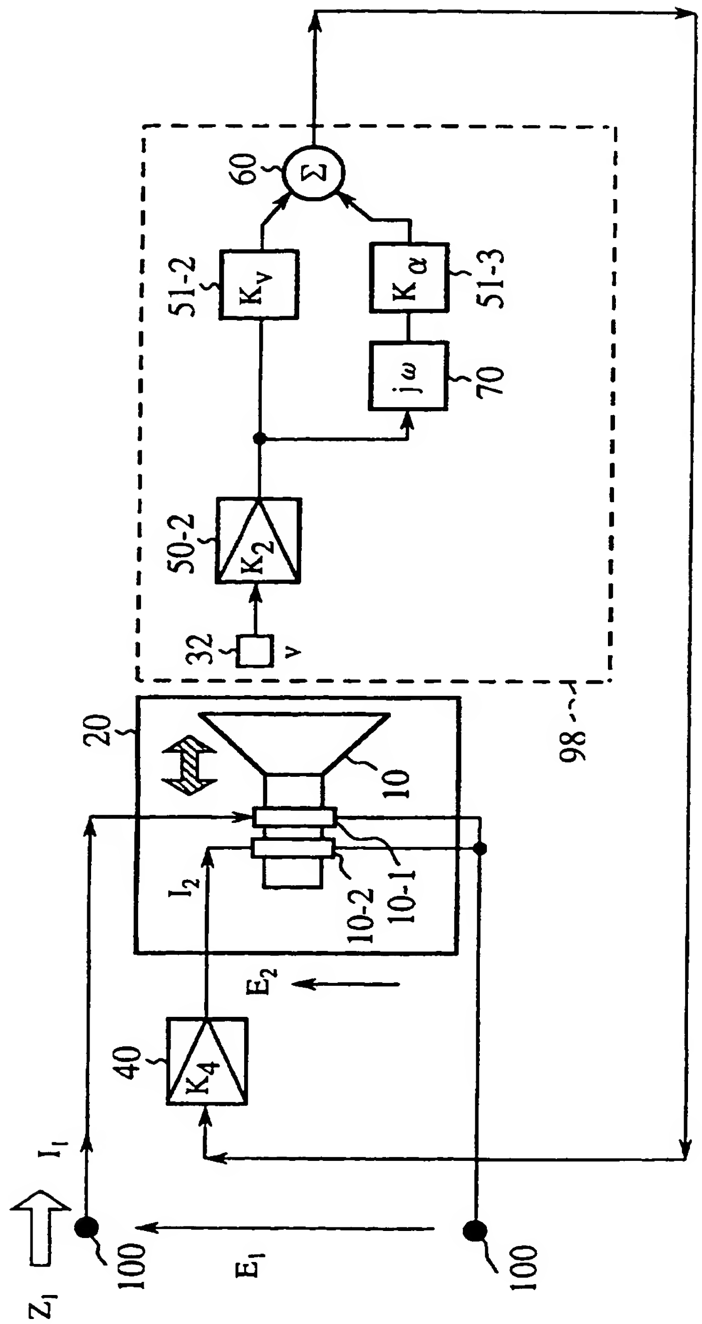

20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100
32
v
50-2
K_2
51-2
K_v
K_α
51-3
$j\omega$
70
60
Σ
98

FIG.20

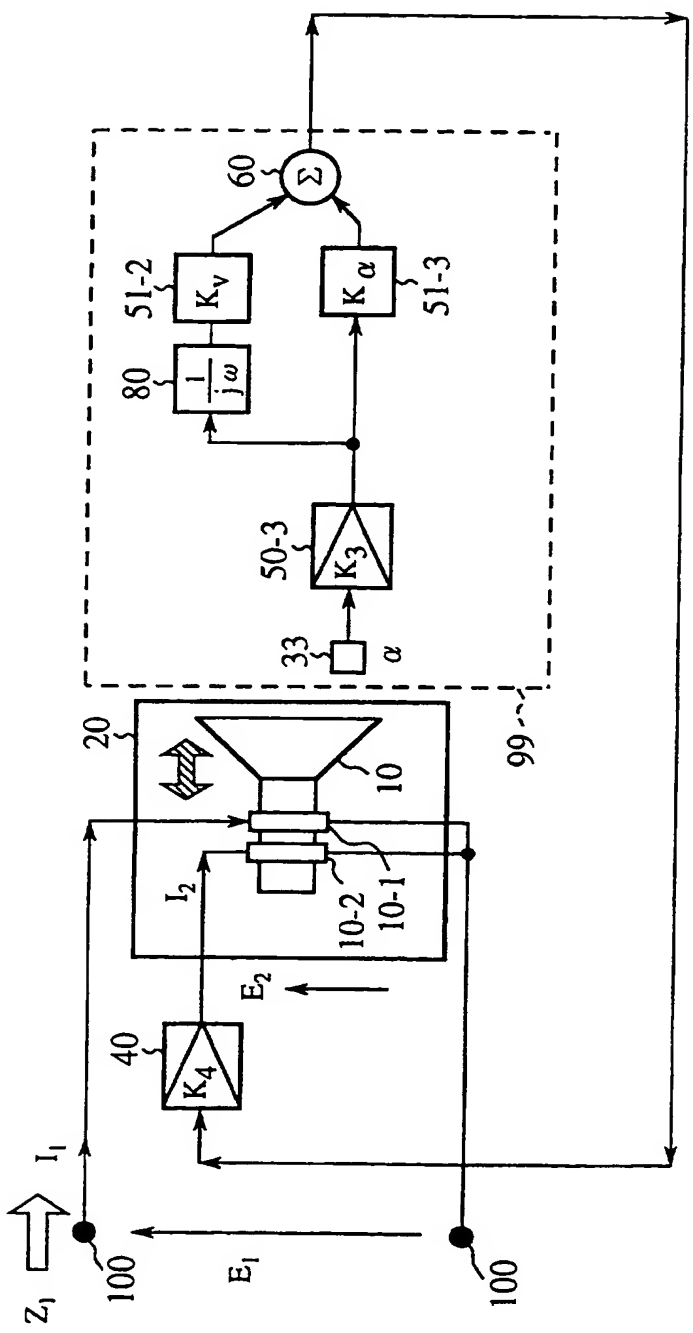
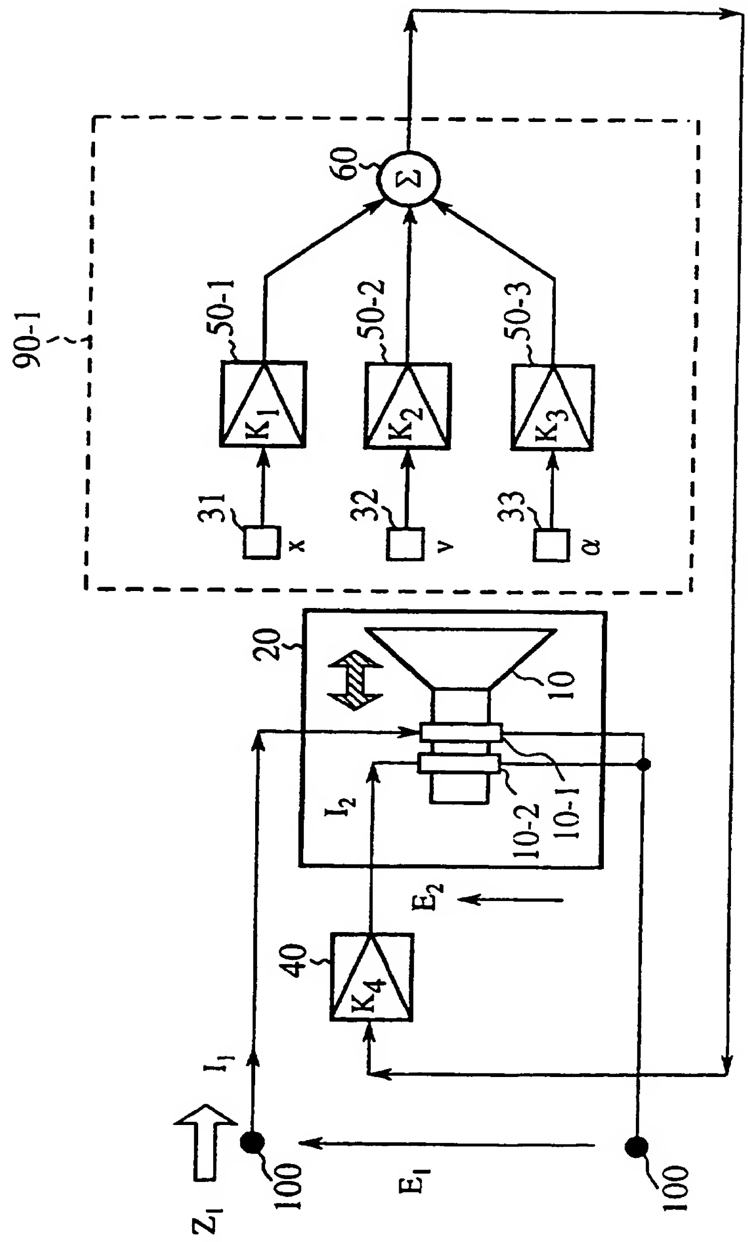
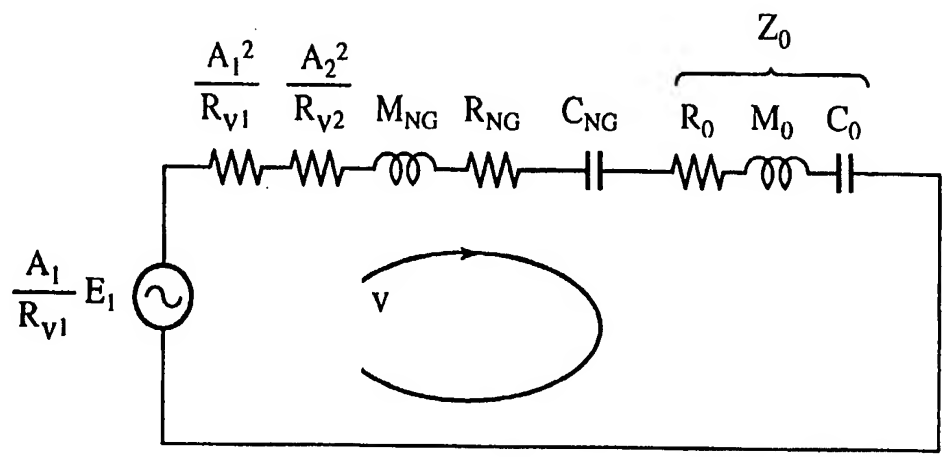

Z1
100
E1
100
I1
40
K4
E2
I2
10-2
10-1
20
10
99
33
α
50-3
K3
80
1/jω
51-2
Kv
Kα
51-3
60
Σ

FIG.21



90-1
31
x
32
v
33
α
K_1
K_2
K_3
50-1
50-2
50-3
60
Σ
20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100

FIG.22

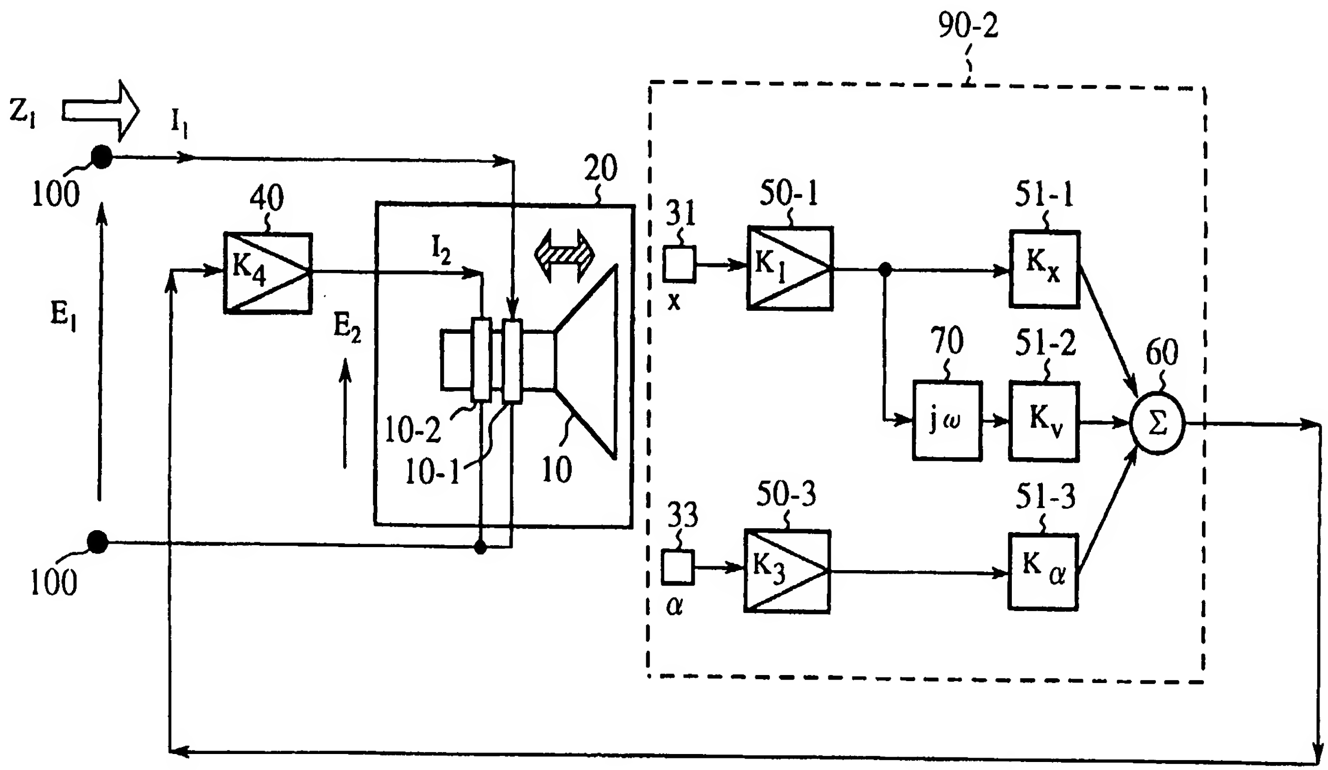


$$C_{NG} = -\frac{R_{V2}}{K_1K_4A_2}$$

$$R_{NG} = -\frac{K_2K_4A_2}{R_{V2}}$$

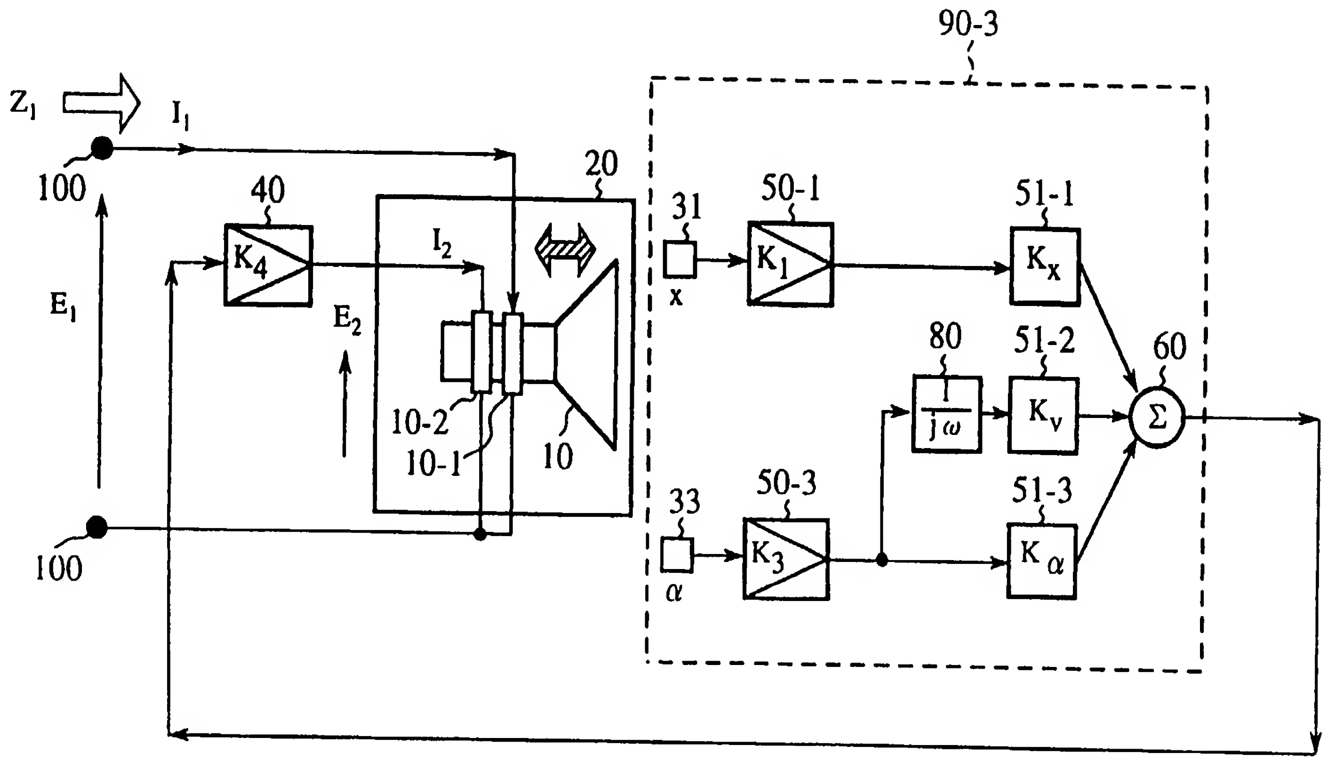
$$M_{NG} = -\frac{K_3K_4A_2}{R_{V2}}$$

FIG.23



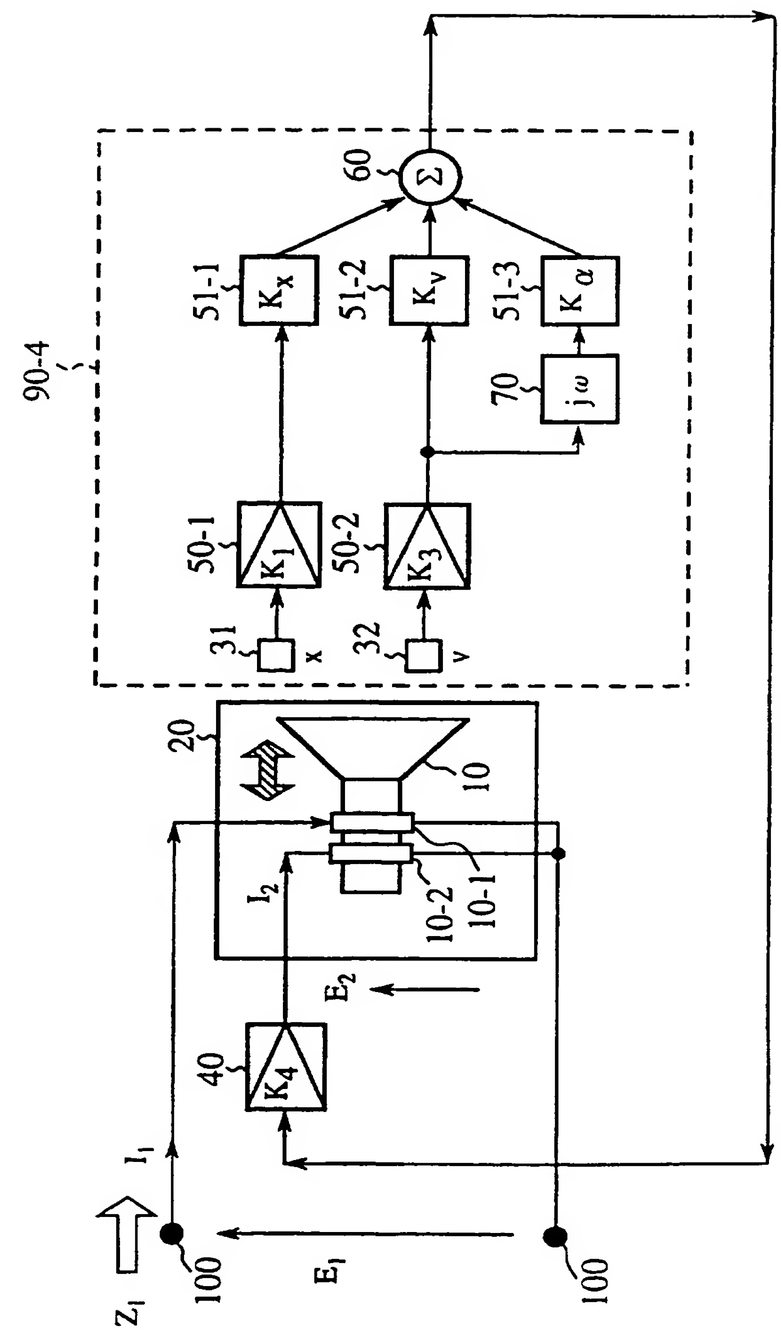
Z1
I1
100
40
K4
E1
I2
E2
20
10-2
10-1
10
100
90-2
31
x
50-1
K1
51-1
Kx
70
jω
51-2
Kv
60
Σ
33
α
50-3
K3
51-3
Kα

FIG.24



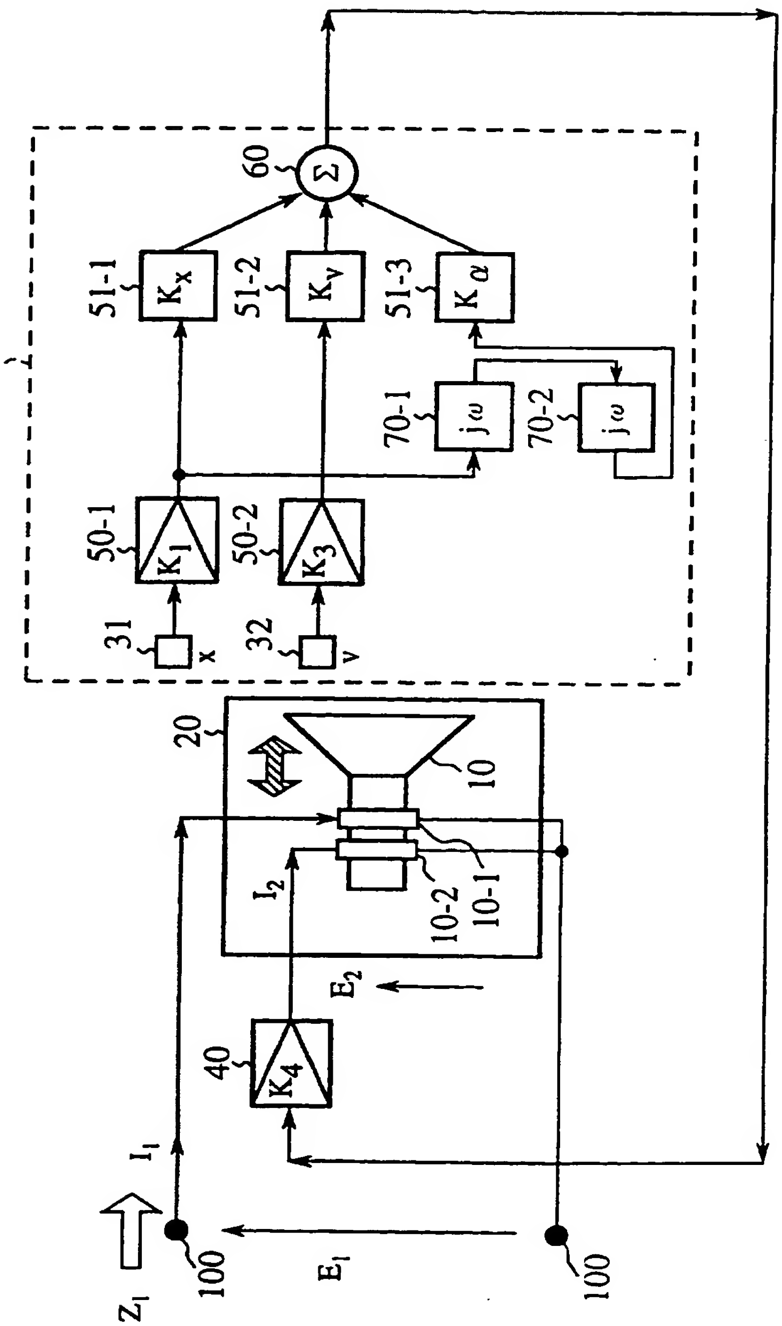
90-3
Z_1
I_1
100
100
E_1
40
K_4
20
I_2
E_2
10-2
10-1
10
31
x
50-1
K_1
51-1
K_x
80
$\frac{1}{j\omega}$
51-2
K_v
60
Σ
33
α
50-3
K_3
51-3
$K\alpha$

FIG.25



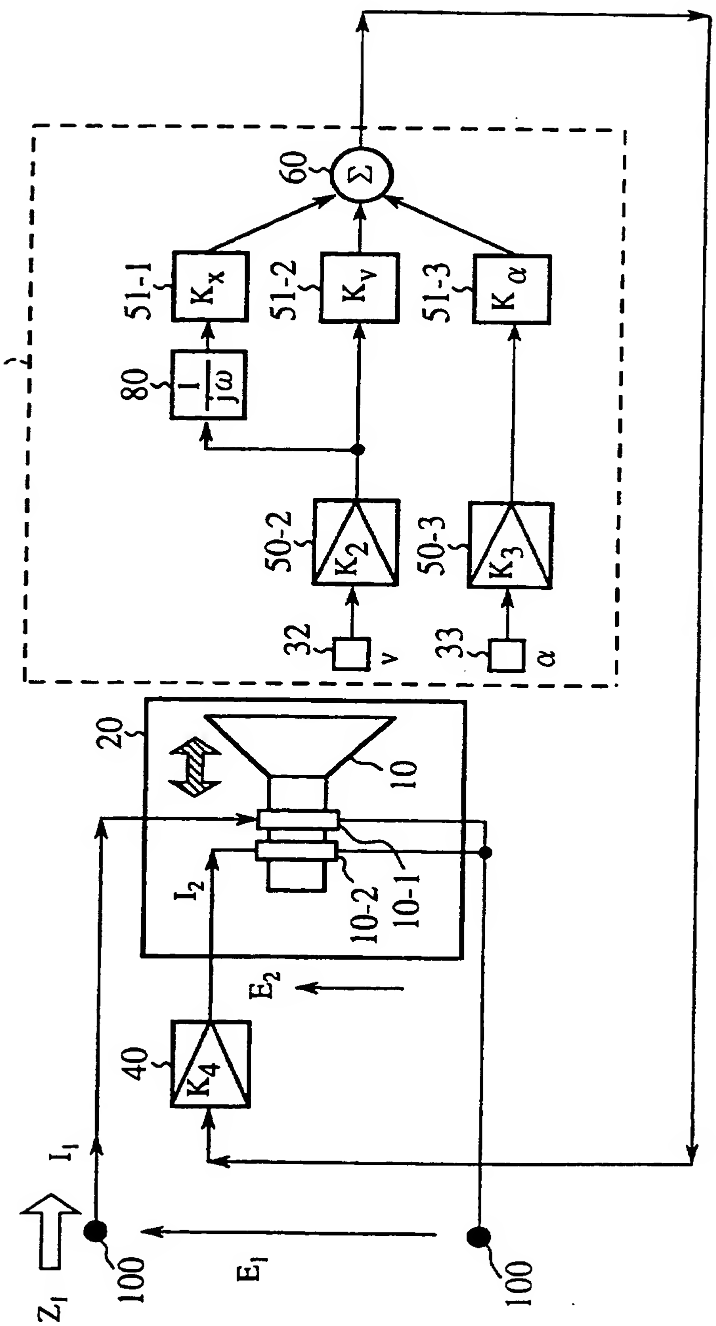
90-4
60
Σ
51-1
K_x
51-2
K_v
51-3
K_α
70
$j\omega$
50-1
K_1
50-2
K_3
31
x
32
v
20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100

FIG.26



90-5
60
Σ
51-1
K_x
51-2
K_v
51-3
K_α
70-1
jω
70-2
jω
50-1
K_1
50-2
K_3
31
x
32
v
20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100

FIG.27


90-6
80
$\frac{1}{j\omega}$
51-1
K_x
51-2
K_v
51-3
K_α
60
Σ
50-2
K_2
50-3
K_3
32
v
33
α
20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100

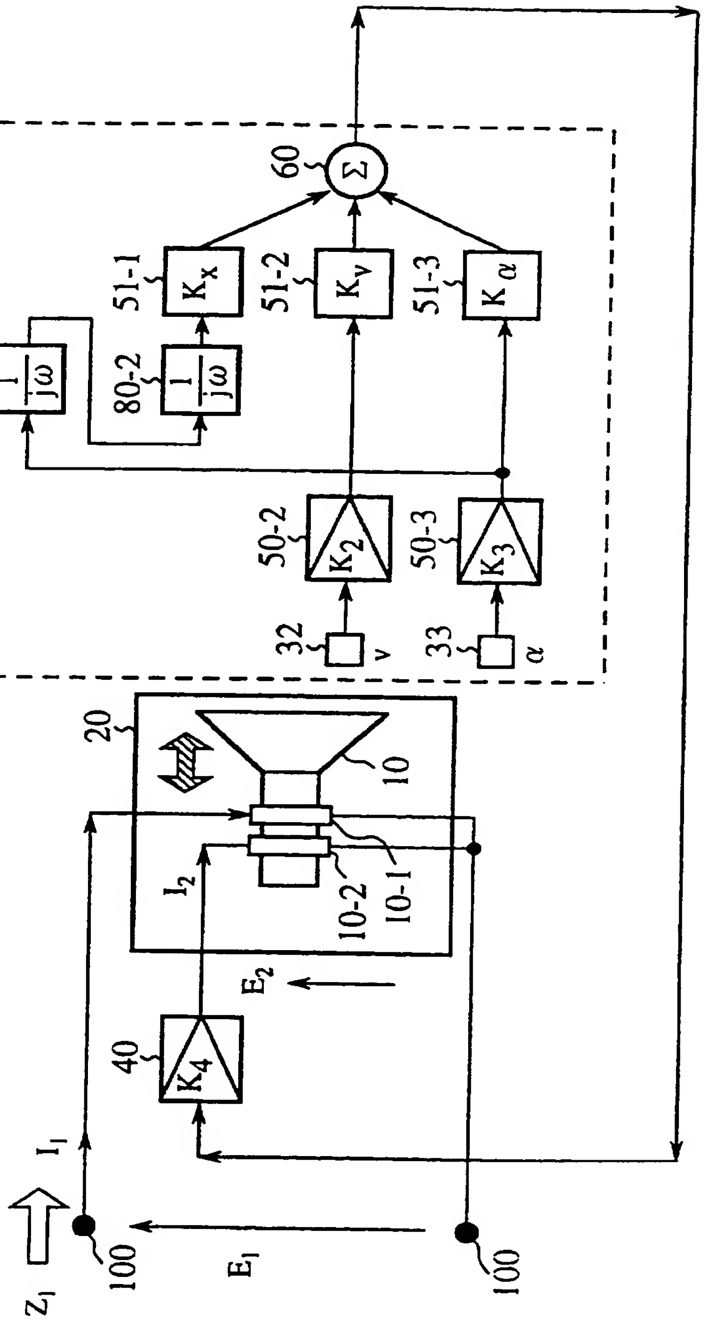
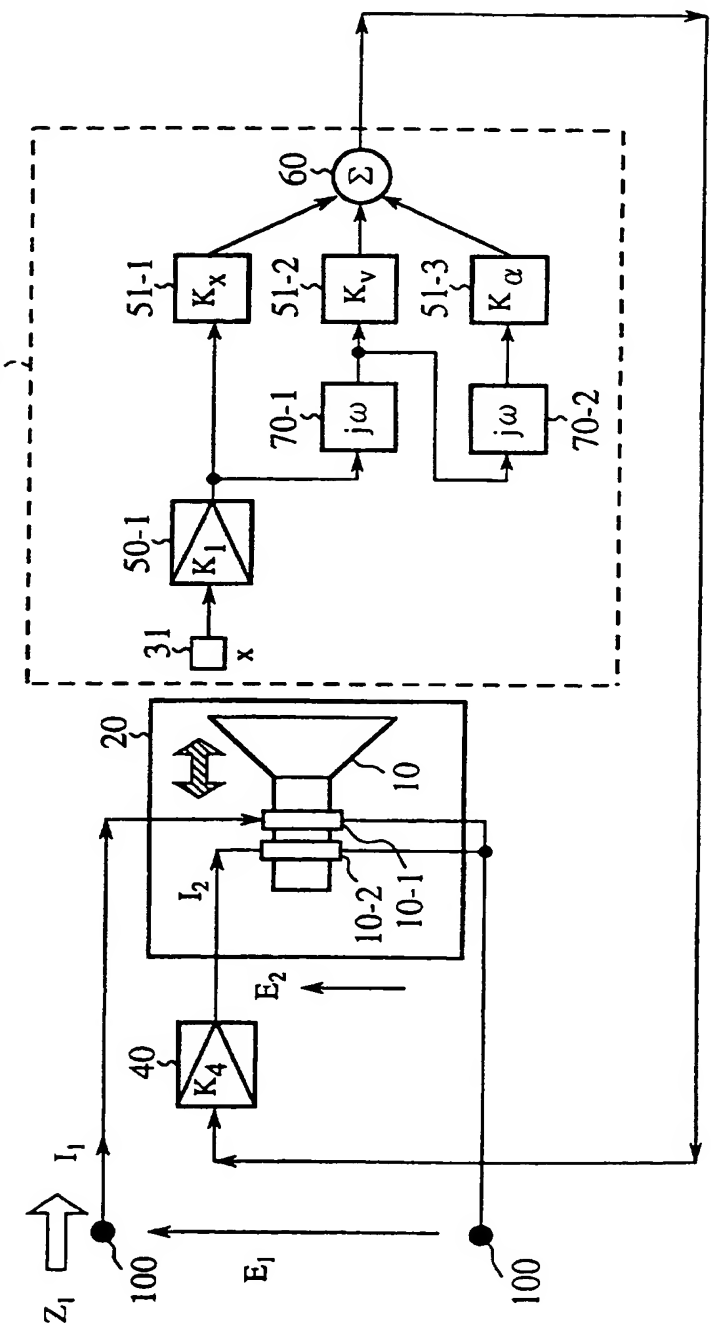
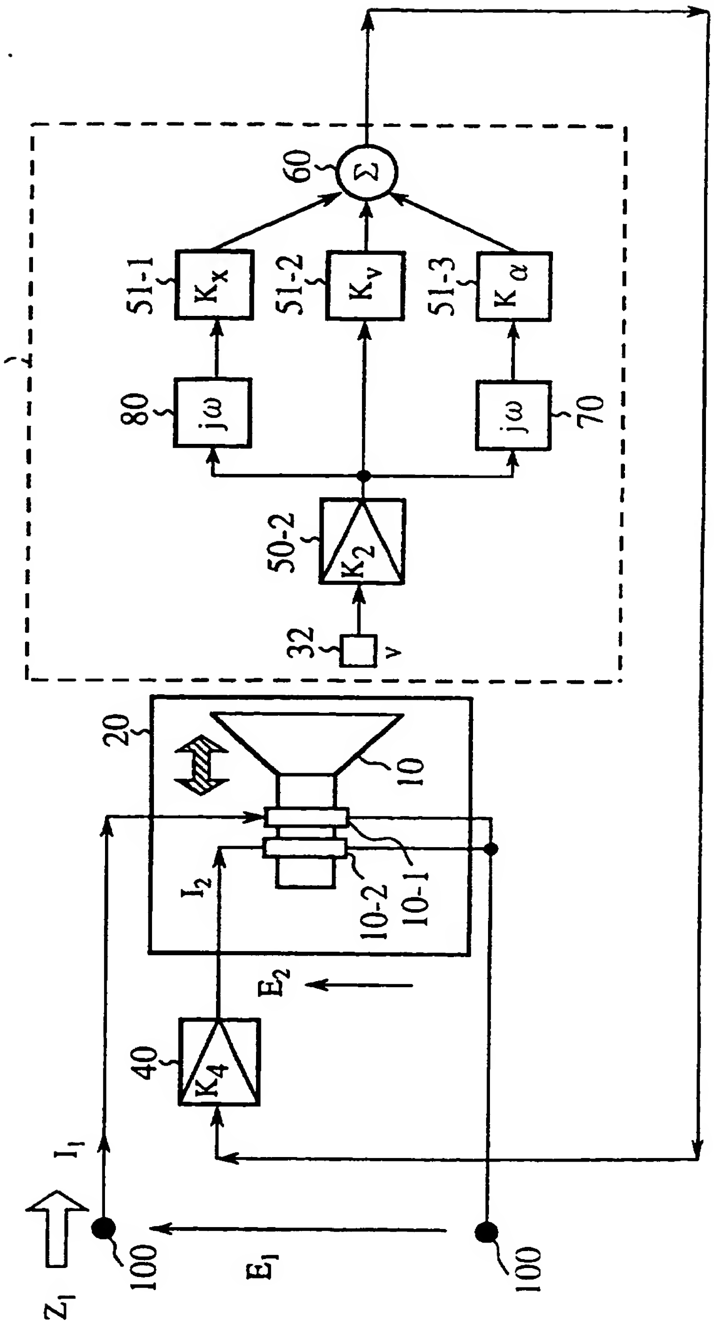

90-7
80-1
80-2
1/jω
51-1
51-2
51-3
K x
K v
K α
60
Σ
50-2
50-3
K2
K3
32
33
v
α
20
10
10-1
10-2
I2
E2
40
K4
I1
Z1
100
E1

FIG.28

FIG.29



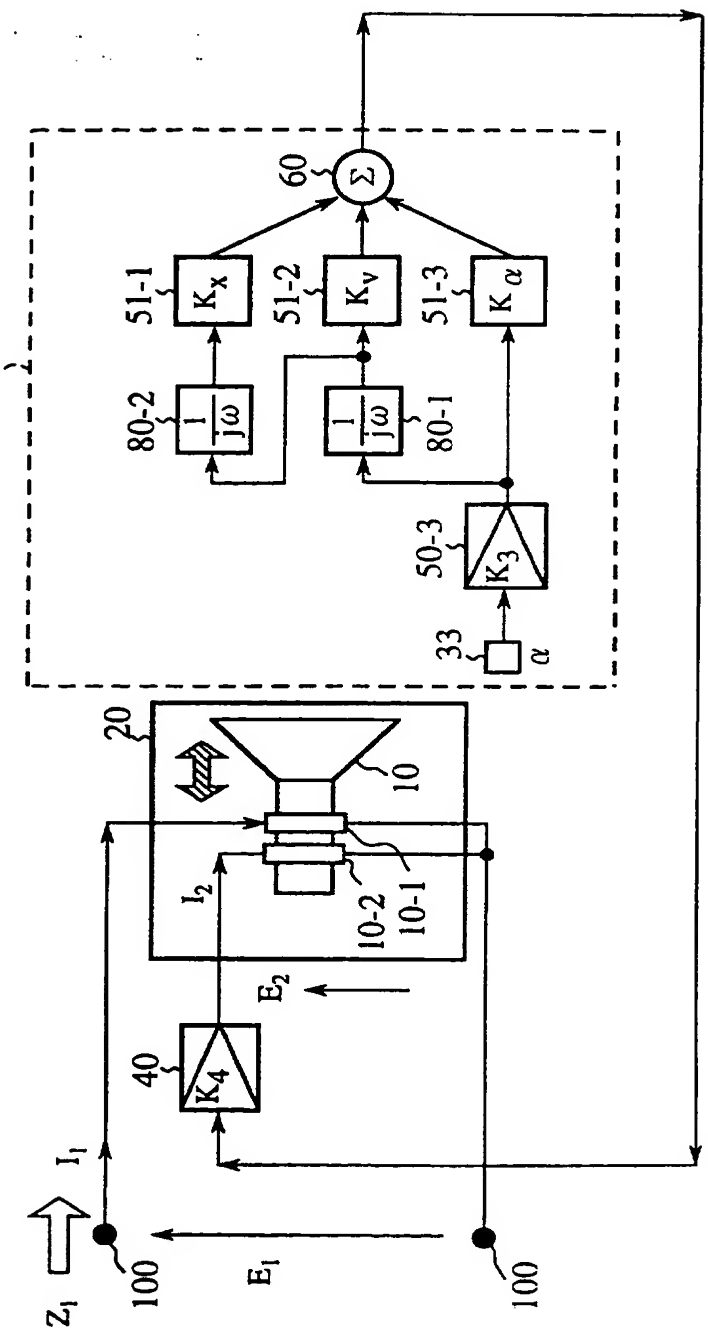
90-8
31
x
50-1
K_1
70-1
$j\omega$
70-2
$j\omega$
51-1
K_x
51-2
K_v
51-3
K_α
60
Σ
20
10
10-1
10-2
I_2
E_2
40
K_4
I_1
Z_1
100
E_1
100



90-9
32
v
50-2
K2
80
jω
70
jω
51-1
Kx
51-2
Kv
51-3
Kα
60
Σ
20
10
10-2
10-1
I2
E2
40
K4
I1
Z1
100
E1
100

FIG.30

FIG.31



TITLE OF THE INVENTION

MFB SPEAKER SYSTEM WITH CONTROLLABLE SPEAKER VIBRATION CHARACTERISTIC

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to motional feedback (MFB) speaker systems and, more particularly, to a MFB speaker system in which the vibration characteristic of a speaker can be arbitrarily controlled and distortion is decreased.

2. Description of the Related Art

Fig. 1 shows a related-art MFB speaker system disclosed in "Speaker System (in 2 volumes)" (Takeo Yamamoto, Radio Technology Publishing, July 15, 1977, p. 406). Referring to Fig. 1, numeral 100 indicates an input terminal of an acoustic signal, 110 indicates an amplifier having a gain of G_A, 120 indicates a feedback circuit having a gain of β, and 130 indicates a speaker having a voltage gain of G_s. E_i indicates an input voltage at the terminal 100, E_v indicates an input voltage supplied to the speaker 130 and E_S indicates an output voltage from the speaker 130.

A description will now given of the operation.

The acoustic signal input via the input terminal 100 is amplified by the amplifier 110 and

drives the speaker 130. The speaker 130 radiates sound as a result of vibration of a diaphragm. The vibration of the diaphragm is detected by a signal detecting means (not shown) provided in the speaker 130 and delivered to the feedback circuit 120. The signal thus fed back is synthesized with the acoustic signal from the input terminal 100 so as to drive the speaker 130.

In this MFB speaker system, the amplifier 110 is used to drive the speaker 130. The amplifier 110 operates in association with the feedback circuit 120 and the speaker 130 so that the entire speaker system operates as a whole. Therefore, it is not generally assumed that a user arbitrarily exchanges the amplifier 110. In the related-art MFB speaker system, the signal returned to the feedback circuit 120 has a negative polarity with respect to the input acoustic signal. Distortion is decreased and the characteristic is improved as a result of the negative feedback.

In the related-art MFB system, the signal detected by the signal detecting means of the speaker 130 may be proportional to the velocity of the diaphragm, to the acceleration of the diaphragm or to the displacement of the diaphragm. Figs. 2A-2C show characteristic of the systems that operate on a velocity signal, an acceleration signal and a displacement signal, respectively, where the frequency is plotted

horizontally and the sound pressure level is plotted vertically.

As shown in Fig. 2A, in the velocity system, when the feedback gain β of the signal proportional to the velocity of the diaphragm (feedback rate D_1) is increased, Q_0 of the speaker system decreases and the sound pressure level in the vicinity of the lowest resonance frequency f_0 is decreased. As shown in Fig. 2B, in the acceleration system, when the feedback gain of the signal proportional to the acceleration of the diaphragm (feedback rate D_2) is increased, the sound pressure level is decreased and Q_0 is increased, though the lowest resonance frequency f_0 of the speaker system is decreased and sound reproduction in the bass region becomes possible.

As shown in Fig. 2C, in the displacement system, the lowest resonance frequency f_0 is increased and Q_0 of the speaker system is increased, when the feedback gain β of the signal proportional to the displacement of the diaphragm (feedback rate D_3) is increased. For the reasons stated above, in the related-art MFB speaker system, an appropriate combination of the signals respectively proportional to the vibration velocity, vibrational acceleration and vibration displacement is often fed back.

Since the related-art MFB speaker system is constructed as described above, the amplifier 110, the speaker 130 and the feedback circuit 120

function as a single system as shown in Fig. 1. Therefore, a user of the speaker system cannot generally use an amplifier in his or her possession. When the amplifier 110 of the MFB speaker system is changed in an attempt to gain high performance, readjustment of the speaker 130 and the feedback circuit 120 is required. Thus, there was generally a problem in that a user cannot exchange an amplifier in the related-art MFB speaker system.

SUMMARY OF THE INVENTION

Accordingly, a general object of the present invention is to provide a MFB speaker system constructed such that a speaker unit having double voice coils is used, the amplifier in the speaker system is used only to amplify a signal from the speaker detected as a result of oscillation of the speaker, and an amplifier in the user's possession or the user's choice may be used as the unit-driving amplifier.

Another and more specific object of the present invention is to provide a MFB speaker system in which double voice-coil speaker unit, used conventionally for bass reproduction, is used, and in which an amplifier for amplifying oscillation information such as vibrational velocity, vibrational acceleration, and vibrational displacement is provided separately from an amplifier for driving the speaker unit

with an acoustic signal, so that a user can use the amplifier in his or her possession or use an amplifier of his or her own choice.

The above objects can be achieved by a MFB speaker system comprising: a speaker unit provided with a first voice coil for inputting an external acoustic signal and a second voice coil for inputting vibrational information obtained by outputting the acoustic signal; vibrational information detecting means for detecting the vibrational information of the speaker unit; and amplifying means for amplifying the vibrational information detected by the vibrational information detecting means and feeding back the vibrational information to the second voice coil with one of a positive and negative polarity with respect to the external acoustic signal.

The vibrational information of the speaker unit may be a signal proportional to a vibrational velocity of a diaphragm of the speaker unit.

The vibrational information of the speaker unit may be a signal proportional to a vibrational acceleration of a diaphragm of the speaker unit.

The vibrational information of the speaker unit may be a signal proportional to a vibrational displacement of a diaphragm of the speaker unit.

The amplifying means may at least

include an amplifier for amplifying only the vibrational information of the speaker unit.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of the speaker unit and a signal proportional to a vibrational velocity of the diaphragm.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of the speaker unit and generate a signal proportional to a vibrational velocity of the diaphragm by differentiating the signal proportional to the vibrational displacement; and the amplifying means may amplify the signal proportional to the vibrational displacement and the signal proportional to the vibrational velocity and feed back the signals to the second voice coil.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of the speaker unit and generate a signal proportional to a vibrational displacement of the diaphragm by integrating the signal proportional to the vibrational velocity; and the amplifying means may amplify the signal proportional to the vibrational displacement and the signal proportional to the vibrational

velocity and feed back the signals to the second voice coil.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of the speaker unit and a signal proportional to a vibrational acceleration of the diaphragm.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of the speaker unit and generate a signal proportional to a vibrational acceleration of the diaphragm by differentiating the signal proportional to the vibrational displacement; and the amplifying means may amplify the signal proportional to the vibrational displacement and the signal proportional to the vibrational acceleration and feed back the signals to the second voice coil.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational acceleration of a diaphragm of the speaker unit and generate a signal proportional to a vibrational displacement of the diaphragm by integrating the signal proportional to the vibrational acceleration; and the amplifying means may amplify the signal proportional to the vibrational displacement and the signal

proportional to the vibrational acceleration and feed back the signals to the second voice coil.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of the speaker unit and a signal proportional to a vibrational acceleration of the diaphragm.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of the speaker unit and generate a signal proportional to a vibrational acceleration of the diaphragm by differentiating the signal proportional to the vibrational velocity; and the amplifying means may amplify the signal proportional to the vibrational velocity and the signal proportional to the vibrational acceleration and feed back the signals to the second voice coil.

The vibrational information detecting means may retrieve, as the vibrational information, a signal proportional to a vibrational acceleration of a diaphragm of the speaker unit and generate a signal proportional to a vibrational velocity of the diaphragm by integrating the signal proportional to the vibrational acceleration; and the amplifying means may amplify the signal proportional to the vibrational velocity and the signal proportional

to the vibrational acceleration and feed back the signals to the second voice coil.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement, vibrational velocity and vibrational acceleration of a diaphragm of the speaker unit, so as to output a sum signal obtained by adding a signal indicating the vibrational displacement, a signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement and vibrational acceleration of a diaphragm of the speaker unit and generate a signal indicating a vibrational velocity by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement and vibrational acceleration of a diaphragm of the speaker unit and generate a signal indicating a vibrational velocity by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating a

vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement and vibrational velocity of a diaphragm of the speaker unit and generate a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational velocity so as to output a sum signal obtained by adding the signal indicating a vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement and vibrational velocity of a diaphragm of the speaker unit and generate a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, a signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational velocity and vibrational acceleration of a diaphragm of the speaker unit and generate a signal indicating a vibrational

displacement by integrating a signal indicating the vibrational velocity so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational velocity and vibrational acceleration of a diaphragm of the speaker unit and generates a signal indicating a vibrational displacement by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, a signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational displacement of a diaphragm of the speaker unit and generate a signal indicating a vibrational velocity and a signal indicating a vibrational acceleration by integrating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information,

a vibrational velocity of a diaphragm of the speaker unit, generate a signal indicating a vibrational displacement by integrating a signal indicating the vibrational velocity and generate a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

The vibrational information detecting means may detect, as the vibrational information, a vibrational acceleration of a diaphragm of the speaker unit and generate a signal indicating a vibrational displacement and a signal indicating a vibrational velocity by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

The vibration information detecting means may adjust the level of a signal indicating the vibrational displacement.

The vibration information detecting means may adjust the level of a signal indicating the vibrational velocity.

The vibration information detecting means may adjust the level of a signal indicating

the vibrational acceleration.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and further features of the present invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings, in which:

Fig. 1 shows the construction of the related-art MFB speaker system;

Figs. 2A-2C are graphs showing the characteristics of the related-art speaker system;

Fig. 3 shows the construction of the MFB speaker system according to a first embodiment;

Fig. 4 is a circuit diagram showing a mechanical equivalent circuit from the perspective of a first voice coil when the speaker system according to the first embodiment is used in a positive feedback setup;

Fig. 5 shows the construction of the MFB speaker system according to a second embodiment;

Fig. 6 is a circuit diagram showing a mechanical equivalent circuit from the perspective of a first voice coil when the speaker system according to the second embodiment is used in a positive feedback setup;

Fig. 7 shows the construction of the MFB speaker system according to a third embodiment;

Fig. 8 is a circuit diagram showing a mechanical equivalent circuit from the perspective

of a first voice coil when the speaker system according to the third embodiment is used in a positive feedback setup;

Fig. 9 shows the construction of the MFB speaker system according to a fourth embodiment;

Fig. 10 is a circuit diagram showing a mechanical equivalent circuit of the MFB speaker system according to the fourth embodiment;

Fig. 11 shows the construction of the MFB speaker system according to a fifth embodiment;

Fig. 12 shows the construction of the MFB speaker system according to a sixth embodiment;

Fig. 13 shows the construction of the MFB speaker system according to a seventh embodiment;

Fig. 14 is a circuit diagram showing a mechanical equivalent circuit of the MFB speaker system according to the seventh embodiment;

Fig. 15 shows the construction of the MFB speaker system according to an eighth embodiment;

Fig. 16 shows the construction of the MFB speaker system according to a ninth embodiment;

Fig. 17 shows the construction of the MFB speaker system according to a tenth embodiment;

Fig. 18 is a circuit diagram showing a

mechanical equivalent circuit of the MFB speaker system according to the tenth embodiment;

Fig. 19 shows the construction of the MFB speaker system according to an eleventh embodiment;

Fig. 20 shows the construction of the MFB speaker system according to a twelfth embodiment;

Fig. 21 shows the construction of the MFB speaker system according to a thirteenth embodiment;

Fig. 22 is a circuit diagram showing a mechanical equivalent circuit of the MFB speaker system according to the thirteenth embodiment;

Fig. 23 shows the construction of the MFB speaker system according to a fourteenth embodiment;

Fig. 24 shows the construction of the MFB speaker system according to a fifteenth embodiment;

Fig. 25 shows the construction of the MFB speaker system according to a sixteenth embodiment;

Fig. 26 shows the construction of the MFB speaker system according to a seventeenth embodiment;

Fig. 27 shows the construction of the MFB speaker system according to an eighteenth embodiment;

Fig. 28 shows the construction of the

MFB speaker system according to a nineteenth embodiment;

Fig. 29 shows the construction of the MFB speaker system according to a twentieth embodiment;

Fig. 30 shows the construction of the MFB speaker system according to a twenty-first embodiment; and

Fig. 31 shows the construction of the MFB speaker system according to a twenty-second embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiment 1

Fig. 3 shows the construction of the MFB speaker system according to the first embodiment. In Fig. 3, numeral 10 indicates a speaker unit, 10-1 indicates a first voice coil of the speaker unit 10 and 10-2 indicates a second voice coil of the speaker unit 10. The speaker unit 10 is of the double voice coil type in which one unit has two voice coils.

Numeral 20 indicates a cabinet, 31 indicates a detecting means for detecting the vibrational velocity v of the speaker unit 10, 51 indicates an amplifier for amplifying a signal proportional to the vibrational velocity v, 40 indicates a power amplifier for driving the second voice coil 10-2 and 100 indicates an input terminal. Symbols E_1, I_1 and Z_1 indicate an input

voltage of the speaker, an input current of the speaker and input impedance of the speaker, respectively. Symbols E_2 and I_2 indicate an input voltage applied to the second voice coil and an input current applied thereto, respectively. Symbol v indicates vibrational velocity of the speaker unit 10. Symbols K_2 and K_4 indicate the gain of the respective amplifiers. The amplifier 51 and the power amplifier 40 constitute amplifying means as claimed.

A description will now be given of the operation.

It is assumed that an externally input acoustic signal is directly applied to the first voice coil 10-1 of the speaker unit 10. That is, it is assumed, for instance, that the signal is input from the amplifier in the user's possession. When this signal is input, the diaphragm of the speaker unit 10 vibrates and vibration information including vibrational velocity v is generated. The vibrational velocity v is detected by the detecting means 31, and the signal proportional to the detected vibrational velocity v is amplified by the amplifiers 51 and 40 before being supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity (positive feedback), a voltage proportional to the vibrational velocity v is

supplied to the second voice coil 10-2. This is equivalent to a decrease of the mechanical resistance of the mechanical equivalent circuit from the perspective of the first voice coil 10-1. In case of a negative polarity (negative feedback), the voltage proportional to the vibrational velocity v is supplied to the second voice coil 10-2 with a negative polarity. This is equivalent to an increase of the mechanical resistance of the mechanical equivalent circuit from the perspective of the first voice coil 10-1.

Fig. 4 is a circuit diagram showing a mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the speaker system with the construction shown in Fig. 3 is used in a positive feedback setup. Referring to Fig. 4, R_{v1} and R_{v2} indicate resistance of the first and second voice coils, respectively. A_1 and A_2 indicate a force factor of the first and second voice coils, respectively. Z_0 indicates mechanical impedance of the speaker unit 10. R_0, M_0, and C_0 indicate equivalent mechanical resistance of the speaker unit, equivalent mass thereof and equivalent mechanical compliance thereof, respectively. R_{NG} indicates negative equivalent mechanical resistance generated as a result of introducing the second voice coil.

Referring to Fig. 4, the negative mechanical resistance R_{NG} varies with the gains K_2 and K_4 of the respective amplifiers. That is, when the

feedback rate for the second voice coil is increased, the negative mechanical resistance R_{NG} is increased in a negative direction so that the mechanical resistance of the speaker system is decreased. When the mechanical resistance is decreased, Q_0 of the mechanical equivalent circuit of the series resonance type is increased.

Although Fig. 4 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, however, the negative equivalent mechanical resistance R_{NG} changes to a positive value and the speaker system operates in the same manner as the related-art velocity MFB system.

Thus, in the MFB speaker system according to the first embodiment, a double voice coil speaker unit is used and a dedicated amplifier which amplifies only the vibrational velocity v is used in the system so that the function to drive the speaker unit is separated from the speaker system. Therefore, the user may couple an amplifier in his or her possession directly with the MFB speaker system and use any amplifier to drive the speaker unit.

Embodiment 2

Fig. 5 shows the construction of the MFB speaker system according to the second embodiment. Referring to Fig. 5, numeral 32 indicates a

detecting means for detecting the vibrational acceleration α of the speaker unit 10, 52 indicates an amplifier for amplifying a signal proportional to the vibrational acceleration α and symbol K_3 indicates a gain of the amplifier. Like numerals and symbols represent like components in Fig. 3 and the description thereof is omitted. The amplifier 52 and the power amplifier 40 constitute amplifying means as claimed.

A description will now be given of the operation.

It is assumed that a signal is applied from a user's amplifier to the first voice coil 10-1 of the speaker unit 10. When this signal is input, the diaphragm of the speaker unit 10 vibrates and vibration information including vibrational acceleration α is generated. The vibrational acceleration α is detected by the detecting means 32, and the signal proportional to the detected vibrational acceleration α is amplified by the amplifiers 52 and 40 before being supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1. When the signal is supplied using a positive feedback, the voltage proportional to the vibrational acceleration α is supplied to the second voice coil 10-2. This is equivalent to a decrease of the equivalent mass of the mechanical equivalent circuit from the perspective of the first voice coil 10-1.

In case of a negative feedback, the voltage proportional to the vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. This is equivalent to an increase of the mechanical resistance of the mechanical equivalent circuit from the perspective of the first voice coil 10-1.

Fig. 6 is a circuit diagram showing a mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the speaker system with the construction shown in Fig. 5 is used in a positive feedback setup.

Referring to Fig. 6, M_{NG} indicates negative equivalent mass generated as a result of introducing the second voice coil. Like numerals and symbols represent like components of Fig. 4 and the description thereof is omitted.

Referring to Fig. 6, the negative equivalent mass M_{NG} varies with the gains K_3 and K_4 of the respective amplifiers. That is, when the feedback rate for the second voice coil 10-2 is increased, the negative equivalent mass M_{NG} is increased in a negative direction so that the equivalent mass of the speaker system is decreased. When the equivalent mass is decreased, Q_0 of the mechanical equivalent circuit of the series resonance type shown in Fig. 5 is decreased so that the sound pressure of the speaker is increased.

Although Fig. 6 shows the mechanical

equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, however, the negative equivalent mass MNC changes to a positive value and the speaker system operates in the same manner as the related-art acceleration MFB system. Thus, in the MFB speaker system according to the second embodiment, a double voice coil speaker unit is used and a dedicated amplifier which amplifies only the vibrational acceleration α is used in the system so that the function to drive the speaker unit is separated from the speaker system.

Therefore, the user may couple an amplifier in his or her possession directly with the MFB speaker system and use any amplifier to drive the speaker unit.

Embodiment 3

Fig. 7 shows the construction of the MFB speaker system according to the third embodiment.

Referring to Fig. 7, numeral 33 indicates a detecting means for detecting the vibrational displacement x of the speaker unit 10, 53 indicates an amplifier for amplifying a signal proportional to the vibrational displacement x and symbol k_1 indicates a gain of the amplifier. Like numerals and symbols represent like components in Fig. 3 and the description thereof is omitted. The amplifier 53 and the power amplifier 40

constitute amplifying means as claimed.

A description will now be given of the operation.

It is assumed that a signal is applied from a user's amplifier to the first voice coil 10-1 of the speaker unit 10. When this signal is input, the diaphragm of the speaker unit 10 vibrates and vibration information including vibrational displacement x is generated. The vibrational displacement x is detected by the detecting means 33, and the signal proportional to the detected vibrational displacement x is amplified by the amplifiers 53 and 40 before being supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1. When the signal is supplied using a positive feedback, the voltage proportional to the vibrational displacement x is supplied to the second voice coil 10-2. This is equivalent to an increase of the equivalent compliance of the mechanical equivalent circuit from the perspective of the first voice coil 10-1.

In case of a negative feedback, the voltage proportional to the vibrational displacement x is supplied to the second voice coil 10-2 with a negative polarity. This is equivalent to a decrease of the equivalent compliance of the mechanical equivalent circuit from the perspective of the first voice coil 10-1.

Fig. 8 is a circuit diagram showing a

mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the speaker system with the construction shown in Fig. 7 is used in a positive feedback setup. Referring to Fig. 8, C_{NG} indicates negative equivalent compliance generated as a result of introducing the second voice coil 10-2. Like numerals and symbols represent like components of Fig. 4 and the description thereof is omitted.

Referring to Fig. 8, the negative compliance C_{NG} varies with the gains k_1 and K_4 of the respective amplifiers. That is, when the feedback rate for the second voice coil 10-2 is increased, the negative equivalent compliance C_{NG} approaches zero from negative infinity so that the equivalent compliance of the speaker system is increased. When the equivalent mass is decreased, Q_0 of the mechanical equivalent circuit of the series resonance type shown in Fig. 8 is decreased so that the lowest resonance frequency of the speaker is increased.

Although Fig. 8 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, however, the negative equivalent compliance C_{NG} changes to a positive value and the speaker system operates in the same manner as the related-art acceleration MFB system.

Thus, in the MFB speaker system

according to the third embodiment, a double voice coil speaker unit is used and a dedicated amplifier which amplifies only the vibrational displacement x is used in the system so that the function to drive the speaker unit is separated from the speaker system. Therefore, the user may couple an amplifier in his or her possession directly with the MFB speaker system and use any amplifier to drive the speaker unit.

Embodiment 4

Fig. 9 shows the construction of the MFB speaker system according to the fourth embodiment. In Fig. 9, numeral 10 indicates a speaker unit, 10-1 indicates a first voice coil of the speaker unit 10 and 10-2 indicates a second voice coil of the speaker unit 10. The speaker unit 10 is of the double voice coil type in which one unit has two voice coils.

Referring to Fig. 9, numeral 20 indicates a cabinet, 31 indicates a vibrational displacement detecting means for detecting the vibrational displacement x of the speaker unit 10, 32 indicates a vibrational velocity detecting means for detecting the vibrational velocity v of the speaker unit 10, 50-1 indicates an amplifier with a gain of k_1 for amplifying the signal indicating the vibration displacement x from the vibrational displacement detecting means 31, 50-2 indicates an amplifier with a gain of K_2 for

amplifying the signal indicating the vibrational velocity v from the vibrational velocity detecting means 32 and 60 indicates an adder for generating a sum signal in which the signals from the amplifiers 50-1 and 50-2 are added.

In this embodiment, the vibrational displacement detecting means 31, the vibrational velocity detecting means 32, the amplifiers 50-1, 50-2 and the adder 60 constitute a vibration information detecting means 91 of the speaker unit 10.

Referring to Fig. 9, numeral 40 indicates a power amplifier (amplifying means) with a gain K_4 for amplifying the sum signal from adder 60 and driving the second voice coil 10-2, 100 indicates an input terminal for inputting an acoustic signal, E_1 and I_1 indicate an input voltage and an input current, respectively, of the speaker unit 10, Z_1 indicates an input impedance of the speaker unit 10, and E_2 and I_2 indicate an input voltage and an input current supplied to the second voice coil 10-2.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates, the

vibrational displacement detecting means 31 outputs the signal indicating the vibrational displacement x as vibration information, and the vibrational velocity detecting means 32 outputs the signal indicating the vibrational velocity v as vibration information.

The signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v are amplified by the amplifier 50-1 and the amplifier 50-2, respectively, to an appropriate level and are added by the adder 60. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational velocity v are added and output from the vibration information detecting means 91 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and the vibrational velocity v is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational velocity v is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

Fig. 10 is a circuit diagram showing a mechanical equivalent circuit of the MFB speaker system according to the fourth embodiment. Referring to Fig. 10, symbols R_{v1} and R_{v2} respectively indicate resistance of the first and second voice coils, A_1 and A_2 respectively indicate force factors of the first and second voice coils, Z_0 indicates mechanical impedance of the speaker unit 10, R_0, M_0 and C_0 indicate equivalent mechanical resistance, equivalent mechanical mass and equivalent mechanical compliance, respectively, of the speaker unit 10. E_1 indicates an input voltage of the first voice coil 10-1, v indicates vibrational velocity, R_{NG} and C_{NG} indicate negative equivalent mechanical resistance and negative mechanical compliance, respectively, generated as a result of introducing the second voice coil 10-2 and positively feeding back the signal proportional to the vibrational velocity v and the

signal proportional to the vibration displacement x.

The negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical compliance C_{NG} are given by the following expressions (1) and (2).

$R_{NG}=-(K_2\ K_4\ A_2\ )/\ R_{v2}$ (1)

$C_{NG}\ =-\ R_{v2}/(k_1\ K_4\ A_2)$ (2)

As demonstrated by the expression (1) above, the negative equivalent mechanical resistance R_{NG} varies with the gains K_2 and K_4 of the amplifiers for amplifying the signal indicating the vibrational velocity v. As demonstrated by the expression (1) above, the negative equivalent mechanical compliance C_{NG} varies with the gains k_1 and K_4 of the amplifiers for amplifying the signal indicating the vibrational displacement x.

That is, if the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical resistance R_{NG} is increased and the negative equivalent mechanical compliance C_{NG} is decreased. Consequently, the equivalent mechanical resistance is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 10 so that neither the entire equivalent mechanical resistance nor equivalent mechanical compliance becomes negative,

thus preventing oscillation of the MFB speaker system.

When the positive feedback as shown in the Fig. 10 is used, Q_0 and the lowest resonance frequency f_0 are given by the following expressions (3) and (4).

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{M_0 C}} = \frac{1}{2\pi}\sqrt{\frac{1}{M_0}\left(\frac{1}{C_{NG}} + \frac{1}{C_0}\right)} \quad \cdots (3)$$

$Q_0 = 2\pi\ f_0\ M_0\ / R_{me}$ (4)

where R_{me} indicates the equivalent mechanical resistance of the mechanical equivalent circuit as a whole. If the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical compliance C_{NG} is decreased so that the lowest resonance frequency f_0 in the expression (3) above drops. Since Q_0 in the expression (4) above varies with f_0 and R_{me}, it varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v.

Although Fig. 10 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system

operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the fourth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 5

Fig. 11 shows the construction of the MFB speaker system according to the fifth embodiment. Referring to Fig. 11, numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the signal indicating the vibrational displacement x from the amplifier 50-1, 70 indicates a differentiator for differentiating the signal indicating the vibrational displacement x from the amplifier 50-1 and generating the signal indicating the vibrational velocity v, and 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the signal indicating the vibrational velocity v from the differentiator 70.

The other aspects of the construction are identical to those shown in Fig. 9 of the fourth embodiment except that the vibrational velocity detecting means 32 and the amplifier 50-2 are eliminated.

In this embodiment, the vibrational displacement detecting means 31, the amplifier 50-1, the differentiator 70, the signal level adjusting means 51-1, 51-2 and the adder 60 constitute a vibration information detecting means 92 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates and the vibrational displacement detecting means 31 outputs the signal indicating the vibrational displacement x as vibration information. The signal is then amplified by the amplifier 50-1 to an appropriate level and diverged into two individual signals. One of the diverged vibrational displacement signals is subject to level adjustment by the signal level adjusting means 51-1 and input to the adder 60.

The other vibrational displacement signal is converted into the signal indicating the

vibrational velocity v by the differentiator 70 and subject to level adjustment by the signal level adjusting means 51-2 before being input to the adder 60. The signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational velocity v are added and output from the vibration information detecting means 92 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational velocity v is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational velocity v is supplied to the second voice coil

10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 11 and the operation thereof are generally the same as disclosed in Fig. 10 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x and the gain K_2 is replaced by the product of k_1 and k_v in Fig. 10.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. Consequentially, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical resistance R_{NG} is increased and the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (1) above. Consequently, the equivalent mechanical resistance

is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 10 so that neither the entire equivalent mechanical resistance nor equivalent mechanical compliance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops as in the fourth embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 10 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x and the gain K_2 is replaced by the product of k_1 and k_v. In the negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the fifth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and

10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 6

Fig. 12 shows the construction of the MFB speaker system according to the sixth embodiment. Referring to Fig. 12, numeral 80 indicates an integrator for integrating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal indicating the vibrational displacement x, 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the signal indicating the vibrational displacement x from the integrator 80 and 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the signal indicating the vibrational velocity v from the amplifier 50-2. The other aspects of the construction are identical to those shown in Fig. 9 of the fourth embodiment except that the vibrational displacement detecting means 31 and the amplifier 50-1 are eliminated.

In this embodiment, the vibrational velocity detecting means 32, the amplifier 50-2, the integrator 80, the signal level adjusting means 51-1, 51-2 and the adder 60 constitute a vibration information detecting means 93 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates and the vibrational velocity detecting means 32 outputs the signal indicating the vibrational velocity v as vibration information. The signal is then amplified by the amplifier 50-2 to an appropriate level and diverged into two individual signals. One of the diverged vibrational velocity signals is subject to level adjustment by the signal level adjusting means 51-2 and input to the adder 60.

The other vibrational velocity signal is converted into the signal indicating the vibrational displacement x by the integrator 80 and subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60. The signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v are added by

the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational velocity v are added and output from the vibration information detecting means 93 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational velocity v is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational velocity v is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 12 and the operation thereof are generally the same as disclosed in Fig. 10 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x and the gain K_2 is replaced by the product of K_2 and k_v in Fig. 10.

The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v, in the signal level adjusting means 51-2 and in the power amplifier 40. Consequentially, the negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational displacement x, in the signal level adjusting means 51-1 and in the power amplifier 40.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical resistance R_{NG} is increased, as demonstrated by the expression (1) above and the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (2) above. Consequently, the equivalent mechanical resistance is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in

the mechanical equivalent circuit shown in Fig. 10 so that neither the entire equivalent mechanical resistance nor equivalent mechanical compliance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops as in the fourth embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational velocity v.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 10 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x and the gain K_2 is replaced by the product of K_2 and k_v. In the negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and displacement MFB system.

Thus, according to the sixth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational velocity v is amplified by the power amplifier 40

and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 7

Fig. 13 shows the construction of the MFB speaker system according to the seventh embodiment. Referring to Fig. 13, numeral 33 indicates a vibrational acceleration detecting means for detecting the vibrational acceleration α of the speaker unit 10 and 50-3 indicates an amplifier with a gain K_3 for amplifying the signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33. The other aspects of the construction are identical to those shown in Fig. 9 of the fourth embodiment except that the vibrational velocity detecting means 32 and the amplifier 50-2 are eliminated.

In this embodiment, the vibrational displacement detecting means 31, the vibrational acceralation detecting means 33, the amplifiers 50-1, 50-3 and the adder 60 constitute a vibration information detecting means 94 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31 and the signal indicating the vibrational acceleration α output from the vibrational acceleration detecting means 33.

The signals are then amplified by the amplifiers 50-1 and 50-3 to an appropriate level and added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 94 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice

coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

Fig. 14 is a circuit diagram showing a mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the MFB speaker system with the construction shown in Fig. 13 is used in a positive feedback setup. Referring to Fig. 14, M_{NG} and C_{NG} indicate negative equivalent mechanical mass and negative equivalent mechanical compliance, respectively, generated as a result of positively feeding back the signal proportional to the vibrational acceleration α and the signal proportional to the vibrational displacement x. Like numerals and symbols represent like components in Fig. 10 and the description thereof is omitted.

The negative equivalent mechanical mass M_{NG} is given by the expression (5) below and the negative equivalent mechanical compliance C_{NG} is given by the expression (2) above.

$M_{NG}=-(K_3\ K_4\ A_2)/\ R_{v2}$ (5)

As demonstrated by the expression (5) above, the negative equivalent mechanical mass M_{NG} varies with the gains K_3 and K_4 of the amplifiers for amplifying the signal indicating the vibrational acceleration α. As demonstrated by the equation (2) above, the negative equivalent mechanical compliance C_{NG} varies with the gains k_1 and K_4 of the amplifiers for amplifying the signal indicating the vibrational displacement x.

That is, if the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical mass M_{NG} is increased, as demonstrated by the expression (5) above, and the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (2) above. Consequently, the equivalent mechanical mass is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 14 so that neither the entire equivalent mechanical mass nor equivalent mechanical compliance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased in the circuit of Fig. 14, the lowest resonance frequency f_0 drops and Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational acceleration α.

Although Fig. 10 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the seventh embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 8

Fig. 15 shows the construction of the MFB speaker system according to an eighth embodiment. Referring to Fig. 15, numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from amplifier the 50-1 and 70-1 indicates a differentiator for differentiating the signal indicating the vibrational displacement x from the amplifier 50-1 and generating the signal indicating the vibrational velocity v. Numeral 70-2 indicates a differentiator for further differentiating the signal indicating the vibrational velocity v from the differentiator 70-1 and generating the signal indicating the vibrational acceleration α and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the signal indicating the vibrational acceleration α from the differentiator 70-2. The other aspects of the construction are identical to those shown in Fig. 13 of the seventh embodiment except that the vibrational acceleration detecting means 33 and the amplifier 50-3 are eliminated.

In this embodiment, the vibrational displacement detecting means 31, the amplifier 50-1, the differentiators 70-1, 70-2, the signal level adjusting means 51-1, 51-3, and the adder 60 constitute a vibration information detecting means 95 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E1, the diaphragm of the speaker unit 10 vibrates. The vibration information is available from the vibrational displacement detecting means 31 as the vibrational displacement x. The signal is then amplified by the amplifier 50-1 to an appropriate level and diverged into two individual signals. One of the diverged vibrational displacement signals is subject to level adjustment by the signal level adjusting means 51-1 and input to the adder 60.

The other vibrational displacement signal is converted into the signal indicating the vibrational acceleration α by the differentiators 70-1 and 70-2 and subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60. The signal indicating the vibrational displacement x and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 95

as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 15 and the operation thereof are generally the same as disclosed in Fig. 14 except that the gain k_1 of the amplifier is

replaced by the product of k_1 and k_x and the gain K_3 is replaced by the product of k_1 and $k\alpha$ in Fig. 10.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x, in the signal level adjusting means 51-1 and in the power amplifier 40. Consequentially, the negative equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational acceleration α, in the signal level adjusting means 51-3 and in the power amplifier 40.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical mass M_{NG} is increased, as demonstrated by the expression (5) above, and the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (2) above. Consequently, the equivalent mechanical resistance is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 14 so that neither the entire equivalent mechanical mass nor equivalent mechanical compliance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops as in the seventh embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 14 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x and the gain K_3 is replaced by the product of k_1 and kα. In the negative feedback, the negative equivalent mechanical mass M_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system operates as a combination of the related-art acceleration MFB system and displacement MFB system.

Thus, according to the eighth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or

use an amplifier of his or her own choice.

Embodiment 9

Fig. 16 shows the construction of the MFB speaker system according to a ninth embodiment. Referring to Fig. 16, numeral 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3, 80-1 indicates an integrator for integrating the signal indicating the vibrational acceleration α from the amplifier 50-3 and generating the signal indicating the vibrational velocity v. 80-2 indicates an integrator for further integrating the signal indicating the vibrational velocity v from the integrator 80-1 and generating the signal indicating the vibrational displacement x and 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the signal indicating the vibrational displacement x from the integrator 80-2. The other aspects of the construction are identical to those shown in Fig. 13 of the seventh embodiment except that the vibrational displacement detecting means 31 and the amplifier 50-1 are eliminated.

That is, the vibrational acceleration detecting means 33, the amplifier 50-3, the integrators 80-1, 80-2, the signal level adjusting means 51-1, 51-3 and the adder 60 constitute a vibration information detecting means 96 of the

speaker unit 10 in this embodiment.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibration information is available from the vibrational displacement detecting means 33 as the vibrational acceleration α. The signal is then amplified by the amplifier 50-3 to an appropriate level and diverged into two individual signals. One of the diverged vibrational acceleration signals is subject to level adjustment by the signal level adjusting means 51-3 and input to the adder 60.

The other vibrational acceleration signal is converted into the signal indicating the vibrational displacement x by being integrated by the integrators 80-1 and 80-2 and subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60. The signal indicating the vibrational displacement x and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x and the signal proportional to the vibrational acceleration α are

added and output from the vibration information detecting means 96 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent compliance and a decrease of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 16 and the operation thereof are generally the same as disclosed in Fig.

14 except that the gain k_1 of the amplifier is replaced by the product of K_3 and k_x and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 14.

The negative equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α, in the signal level adjusting means 51-3 and in the power amplifier 40. Consequentially, the negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational displacement x, in the signal level adjusting means 51-1 and in the power amplifier 40.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical mass M_{NG} is increased, as demonstrated by the expression (5) above, and the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (2) above. Consequently, the equivalent mechanical mass is decreased and the equivalent mechanical compliance is increased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 14 so that neither the entire equivalent mechanical mass nor equivalent mechanical compliance becomes negative, thus

preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops as in the seventh embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 14 except that the gain k_1 of the amplifier is replaced by the product of K_3 and k_x and the gain K_3 is replaced by the product of K_3 and kα. In the negative feedback, the negative equivalent mechanical mass M_{NG} and the negative equivalent mechanical compliance C_{NG} change to a positive value and the speaker system operates as a combination of the related-art acceleration MFB system and displacement MFB system.

Thus, according to the ninth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can

use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 10

Fig. 17 shows the construction of the MFB speaker system according to the tenth embodiment. Referring to Fig. 17, numeral 33 indicates a vibrational acceleration detecting means for detecting the vibrational acceleration α of the speaker unit 10 and 50-3 indicates an amplifier with a gain K_3 for amplifying the signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33. The other aspects of the construction are identical to those shown in Fig. 9 of the fourth embodiment except that the vibrational displacement detecting means 31 and the amplifier 50-1 are eliminated.

That is, the vibrational velocity detecting means 32, the vibrational acceleration detecting means 33, the amplifiers 50-2, 50-3 and the adder 60 constitute a vibration information detecting means 97 of the speaker unit 10 in this embodiment.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the

speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational velocity v output from the vibrational velocity detecting means 32 and the signal indicating the vibrational acceleration α output from the vibrational acceleration detecting means 33.

The signals are then amplified by the amplifiers 50-2 and 50-3 to an appropriate level and added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 97 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical

equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

Fig. 18 is a circuit diagram showing a mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the MFB speaker system with the construction shown in Fig. 17 is used in a positive feedback setup. Referring to Fig. 18, R_{NG} and M_{NG} indicate negative equivalent mechanical resistance and negative equivalent mechanical mass, respectively, generated as a result of positively feeding back the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α.

The negative equivalent mechanical resistance R_{NG} is given by the expression (1) above and the negative equivalent mechanical mass M_{NG} is given by the expression (5) above. The negative equivalent mechanical resistance R_{NG} varies with the gains K_2 and K_4 of the amplifiers for amplifying the signal indicating the vibrational

velocity v. The negative equivalent mechanical mass M_{NG} varies with the gains K_3 and K_4 of the amplifiers for amplifying the signal indicating the vibrational acceleration α.

That is, if the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical mass M_{NG} is increased, as demonstrated by the expression (5) above, and the negative equivalent mechanical resistance R_{NG} is increased, as demonstrated by the expression (1) above. Consequently, the equivalent mechanical mass and the equivalent mechanical resistance are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 18 so that neither the entire equivalent mechanical mass nor equivalent mechanical resistance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased in the circuit of Fig. 18, the lowest resonance frequency f_0 rises and Q_0 varies with the feedback rate of the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

Although Fig. 18 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In the negative feedback, the negative

equivalent mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the tenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational velocity v and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 11

Fig. 19 shows the construction of the MFB speaker system according to the eleventh embodiment. Referring to Fig. 19, numeral 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the signal indicating the vibrational velocity v from the amplifier 50-2, 70 indicates a differentiator for differentiating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal indicating the vibrational acceleration α and 51-3

indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the signal indicating the vibrational acceleration α from the differentiator 70. The other aspects of the construction are identical to those shown in Fig. 10 of the tenth embodiment except that the vibrational acceleration detecting means 33 and the amplifier 50-3 are eliminated.

That is, in this embodiment, the vibrational velocity detecting means 32, the amplifier 50-2, the differentiator 70, the signal level adjusting means 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 98 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E1, the diaphragm of the speaker unit 10 vibrates and the vibrational velocity detecting means 32 outputs the signal indicating the vibrational velocity v as vibration information. The signal is then amplified by the amplifier 50-2 to an appropriate level and diverged into two individual signals. One of the diverged vibrational velocity signals is subject to level adjustment by the signal level adjusting means 51-2 and input to the adder 60.

The other vibrational velocity signal is converted into the signal indicating the vibrational acceleration α by the differentiator 70 and subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60. The signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 98 as a sum signal.

After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up

so that the input voltage E_2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 19 and the operation thereof are generally the same as disclosed in Fig. 18 except that the gain K_2 of the amplifier is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of K_2 and $k\alpha$ in Fig. 18.

The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v, in the signal level adjusting means 51-2 and in the power amplifier 40. Consequentially, the negative equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational acceleration α, in the signal level adjusting means 51-3 and in the power amplifier 40.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical

resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expressions (1) and (5) above. Consequently, the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 18 so that neither the entire equivalent mechanical mass nor equivalent mechanical resistance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 rises as in the tenth embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 17 except that the gain K_2 of the amplifier is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of K_2 and $k\alpha$. In the negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the eleventh embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational velocity v and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 12

Fig. 20 shows the construction of the MFB speaker system according to the twelfth embodiment. Referring to Fig. 20, numeral 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the signal indicating the vibrational acceleration α from the amplifier 50-3, 80 indicates an integrator for integrating the signal indicating the vibrational acceleration α from the amplifier 50-3 and generating the signal indicating the vibrational velocity v and 51-2 is signal level adjusting means with a gain k_v for adjusting the signal indicating the vibrational velocity v from the integrator 80 is adjusted. The other aspects of the construction are identical to those shown in Fig. 17 of the tenth

embodiment except that the vibrational velocity detecting means 32 and the amplifier 50-2 are eliminated.

That is, in this embodiment, the vibrational acceleration detecting means 33, the amplifier 50-3, the integrator 80, the signal level adjusting means 51-2, 51-3, and the adder 60 constitute a vibration information detecting means 99 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates and the vibrational acceleration detecting means 33 outputs the signal indicating the vibrational acceleration α as vibration information The signal is then amplified by the amplifier 50-3 to an appropriate level and diverged into two individual signals. One of the diverged vibrational acceleration signals is subject to level adjustment by the signal level adjusting means 51-3 and input to the adder 60.

The other vibrational acceleration signal is converted into the signal indicating the vibrational velocity v by the integrator 80 and subject to level adjustment by the signal level

adjusting means 51-2 before being input to the adder 60. The signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 99 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is

equivalent to an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 20 and the operation thereof are generally the same as disclosed in Fig. 18 except that the gain K_2 of the amplifier is replaced by the product of K_3 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 18. The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α, in the signal level adjusting means 51-3 and in the power amplifier 40. Consequentially, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational velocity v, in the signal level adjusting means 51-2 and in the power amplifier 40.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expressions (1) and (5) above. Consequently, the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system.

When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 18 so that neither the entire equivalent mechanical mass nor equivalent mechanical resistance becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 rises as in the seventh embodiment and Q_0 varies with the feedback rate of the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 17 except that the gain K_2 of the amplifier is replaced by the product of K_3 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} change to a positive value and the speaker system operates as a combination of the related-art velocity MFB system and acceleration MFB system.

Thus, according to the twelfth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational velocity v and vibrational

acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 13

Fig. 21 shows the construction of the MFB speaker system according to the thirteenth embodiment. In Fig. 21, numeral 10 indicates a speaker unit, 10-1 indicates a first voice coil of the speaker unit 10 and 10-2 indicates a second voice coil of the speaker unit 10. The speaker unit 10 is of the double voice coil type in which one unit has two voice coils.

Referring to Fig. 21, numeral 20 indicates a cabinet, 31 indicates a vibrational displacement detecting means for detecting the vibrational displacement x of the speaker unit 10, 32 indicates a vibrational velocity detecting means for detecting the vibrational velocity v of the speaker unit 10 and 33 indicates a vibrational acceleration detecting means for detecting the vibrational acceleration α of the speaker unit 10. Numeral 50-1 indicates an amplifier with a gain k_1 for amplifying the signal indicating the vibrational displacement x from the vibrational displacement detecting means 31, 50-2 indicates an

amplifier for amplifying the signal indicating the vibrational velocity v from the vibrational velocity detecting means 32, 50-3 indicates an amplifier for amplifying the signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33 and 60 indicates an adder for generating the sum signal composed of the signals from the amplifiers 50-1, 50-2 50-3.

That is, in this embodiment, the vibrational displacement detecting means 31, the vibrational velocity detecting means 32, the vibrational acceleration detecting means 33, the amplifiers 50-1, 50-2 and 50-3, and the adder 60 constitute a vibration information detecting means 90-1 of the speaker unit 10.

Referring to Fig. 21, 40 indicates a power amplifier (amplifying means) with a gain K_4 for amplifying the sum signal from the adder 60 and driving the second voice coil 10-2, 100 indicates an input terminal for inputting the acoustic signal, E_1 and I_1 indicate an input voltage and an input current, respectively, supplied to the speaker unit 10, Z_1 indicates an input impedance of the speaker unit 10 and E_2 and I_2 indicate an input voltage and an input current, respectively, supplied to the second voice coil 10-2.

A description will now be given of the operation.

For example, when an acoustic signal

amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31, the signal indicating the vibrational velocity v output from the vibrational velocity detecting means 32 and the signal indicating the vibrational acceleration α output from the vibrational acceleration detecting means 33.

The signals are then amplified by the amplifiers 50-1, 50-2 and 50-3, respectively, to an appropriate level and added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-1 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up

so that the input voltage E2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase in equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

Fig. 22 is a circuit diagram showing a mechanical equivalent circuit from the perspective of the first voice coil 10-1 when the MFB speaker system with the construction shown in Fig. 21 is used in a positive feedback setup. Referring to Fig. 22, symbols R_{v1} and R_{v2} indicate the resistance of first and second voice coils, A_1 and A_2 indicate the force factors of first and second

voice coils, Z_0 indicates the mechanical impedance of the speaker unit 10, R_0, M_0 and C_0 indicate the equivalent mechanical resistance, equivalent mechanical mass and equivalent mechanical compliance of the speaker unit 10. Symbol E_1 indicates an input voltage supplied to the first voice coil 10-1, v indicates the vibrational velocity, C_{NG}, R_{NG} and M_{NG} indicate the negative equivalent mechanical compliance, the negative equivalent mechanical resistance, the negative equivalent mechanical mass generated as a result of introducing the second voice coil 10-2 and positively feeding back the signals respectively proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α.

The negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are given by the following expressions (6), (7) and (8).

$C_{NG}=- R_{v2}/(k_1\ K_4\ A_2)$ (6)

$R_{NG}=- K_2\ K_4\ A_2\ /\ R_{v2}$ (7)

$M_{NG}=- K_3\ K_4\ A_2\ /\ R_{v2}$ (8)

As demonstrated by the expression (6) above, the negative equivalent mechanical compliance C_{NG} varies with the gains k_1 and K_4 of the amplifiers. As demonstrated by the expressions (7) and (8) above, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG}

vary with the gains K_2 and K_4 of the amplifiers and with the gains K_3 and K_4 of the amplifiers.

That is, if the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical compliance C_{NG} is decreased, and the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} are increased. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and the negative mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

When the positive feedback as shown in the Fig. 22 is used, Q_0 and the lowest resonance frequency f_0 are given by the following expressions (9) and (10).

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{M_0}\left(\frac{1}{C_{NG}}+\frac{1}{C_0}\right)} \qquad (4)$$

$Q_0 = 2\pi f_0 M_0 / R_{me}$ (10)

where R_{me} indicates the equivalent mechanical resistance of the mechanical equivalent circuit as

a whole. If the feedback to the second voice coil 10-2 is increased, the negative equivalent mechanical compliance C_{NG} is decreased so that the lowest resonance frequency f_0 in the expression (9) above drops assuming that the equivalent mechanical mass M_0 remains constant. Since Q_0 in the expression (10) above varies with f_0, M_0 and R_{me}, it varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

Although Fig. 22 shows the mechanical equivalent circuit for a positive feedback, the same circuit construction applies to a negative feedback. In a negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the thirteenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is

amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 14

Fig. 23 shows the construction of the MFB speaker system according to the fourteenth embodiment. Referring to Fig.23, numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the amplifier 50-1, 70 indicates a differentiator for differentiating the signal indicating the vibrational displacement x from the amplifier 50-1 and generating the signal indicating the vibrational velocity v. Numeral 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the differentiator 70, 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational velocity detecting means 32 and the

amplifier 50-2 are eliminated.

That is, in this embodiment, the vibrational displacement detecting means 31, the vibrational acceleration detecting means 33, the amplifiers 50-1, 50-3, the differentiator 70, the signal level adjusting means 51-1, 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 90-2 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31 and the signal indicating the vibrational acceleration α output from the vibrational acceleration detecting means 33.

The signal indicating the vibrational displacement x is then amplified by the amplifier 50-1 to an appropriate level and diverged into two individual signals. One of the diverged vibrational displacement signals is subject to level adjustment by the signal level adjusting means 51-1 and input to the adder 60. The other

vibrational displacement signal is converted into the signal indicating the vibrational velocity v by the differentiator 70 and subject to level adjustment by the signal level adjusting means 51-2 before being input to the adder 60.

The signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33 is amplified by the amplifier 50-3 to an appropriate level and subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-2 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v

and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 23 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 22. The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting

means 51-1. Consequentially, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2, and the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expressions (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency

f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of k_1 and k_v, and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the fourteenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signals respectively proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic

signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 15

Fig. 24 shows the construction of the MFB speaker system according to the fifteenth embodiment. Referring to Fig. 24, numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the amplifier 50-1, 80 indicates an integrator for integrating the signal indicating the vibrational acceleration α from the amplifier 50-3 and generating the signal indicating the vibrational velocity v. Numeral 51-2 is a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the integrator 80 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational velocity detecting means 32 and the amplifier 50-2 are eliminated.

That is, in this embodiment, the

vibrational displacement detecting means 31, the vibrational acceleration detecting means 33, the amplifiers 50-1, 50-3, the integrator 80, the signal level adjusting means 51-1, 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 90-3 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31 and the signal indicating the vibrational acceleration α output from the vibrational acceleration detecting means 33.

The signal indicating the vibrational displacement x from the vibrational displacement detecting means 31 is then amplified by the amplifier 50-1 to an appropriate level and subject to level conversion by the signal level adjusting means 51-1.

The signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33 is amplified by the amplifier

50-3 to an appropriate level and diverged into two individual signals. One of the diverged vibrational acceleration signals is subject to level adjustment by the signal level adjusting means 51-3 and input to the adder 60. The other vibrational acceleration signal is converted into the signal indicating the vibrational velocity v by the integrator 80 and subject to level adjustment by the signal level adjusting means 51-2 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-3 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v

and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 24 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_3 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the

amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. Consequentially, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2, and the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expressions (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus

preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_3 and k_v, and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the fifteenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal proportional to the vibrational displacement x, the signal indicating

the vibrational velocity v obtained by integrating the signal indicating the vibrational acceleration α, and the signal indicating the vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 16

Fig. 25 shows the construction of the MFB speaker system according to the sixteenth embodiment. Referring to Fig. 25, numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the amplifier 50-1 and 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the amplifier 50-2. Numeral 70 indicates a differentiator for differentiating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal indicating the vibrational acceleration α and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the differentiator 70. The other aspects of the

construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational acceleration detecting means 33 and the amplifier 50-3 are eliminated.

That is, in this embodiment, the vibrational displacement detecting means 31, the vibrational velocity detecting means 32, the amplifiers 50-1, 50-2, the differentiator 70, the signal level adjusting means 51-1, 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 90-4 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31 and the signal indicating the vibrational velocity v output from the vibrational velocity detecting means 32.

The signal indicating the vibrational displacement x from the vibrational displacement detecting means 31 is amplified by the amplifier 50-1 to an appropriate level and subject to level

conversion by the signal level adjusting means 51-1 before being input to the adder 60.

The signal indicating the vibrational velocity v from the vibrational velocity detecting means 33 is amplified by the amplifier 50-2 to an appropriate level and diverged into two individual signals. One of the diverged vibrational velocity signals is subject to level adjustment by the signal level adjusting means 51-2 and input to the adder 60. The other vibrational velocity signal is converted into the signal indicating the vibrational acceleration α by the differentiator 70 and subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-4 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 25 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_2 and k_v and the

gain K_3 is replaced by the product of K_2 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2. Consequently, the equivalent mechanical mass v changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the

mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_2 and k_v, and the gain K_3 is replaced by the product of K_2 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the sixth embodiment, the speaker unit 10 of the double voice coil type

having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal proportional to the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α obtained by differentiating the signal indicating the vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 17

Fig. 26 shows the construction of the MFB speaker system according to the seventeenth embodiment. Referring to Fig. 26, numerals 70-1 and 70-2 indicates differentiators for twice-differentiating the signal indicating the vibrational displacement x from the amplifier 50-1 and generating the signal indicating the vibrational acceleration α and 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the amplifier 50-1. Numeral 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v

from the amplifier 50-2 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α generated by the differentiators 70-1 and 70-2. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational acceleration detecting means 33 and the amplifier 50-3 are eliminated.

That is, in this embodiment, the vibrational displacement detecting means 31, the vibrational velocity detecting means 32, the amplifiers 50-1, 50-2, the differentiators 70-1, 70-2, the signal level adjusting means 51-1, 51-2, 51-3, and the adder 60 constitute a vibration information detecting means 90-5 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31 and the signal indicating the vibrational velocity v

output from the vibrational velocity detecting means 32.

The signal indicating the vibrational displacement x is then amplified by the amplifier 50-1 to an appropriate level and diverged into two individual signals. One of the diverged vibrational displacement signals is subject to level adjustment by the signal level adjusting means 51-1 and input to the adder 60.

The other vibrational displacement signal is converted into the signal indicating the vibrational acceleration α by being differentiated twice by the differentiators 70-1 and 70-2, and is then subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational velocity v from the vibrational velocity detecting means 32 is amplified by the amplifier 50-2 to an appropriate level and subject to level adjustment by the signal level adjusting means 51-2 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional

to the vibrational acceleration α are added and output from the vibration information detecting means 90-6 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the

entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 26 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of k_1 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2. Consequently, the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass v are increased, as demonstrated

by the expressions (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of K_2 and k_v, and the gain K_3 is replaced by the product of k_1 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent

mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the seventeenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α obtained by differentiating the signal indicating the vibrational displacement x twice is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 18

Fig. 27 shows the construction of the MFB speaker system according to the eighteenth embodiment. Referring to Fig. 27, numeral 80 indicates an integrator for integrating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal

indicating the vibrational displacement x and 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the integrator 80. Numeral 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the amplifier 50-2 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational displacement detecting means 31 and the amplifier 50-1 are eliminated.

That is, in this embodiment, the vibrational velocity detecting means 32, the vibrational acceleration detecting means 33, the amplifiers 50-2, 50-3, the integrator 80, the signal level adjusting means 51-1, 51-2, 51-3, and the adder 60 constitute a vibration information detecting means 90-6 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the

diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational velocity v output from the vibrational displacement detecting means 32 and the signal indicating the vibrational acceleration α output from the vibrational velocity detecting means 33.

The signal indicating the vibrational velocity v is then amplified by the amplifier 50-2 to an appropriate level and diverged into two individual signals. One of the diverged vibrational velocity signals is subject to level adjustment by the signal level adjusting means 51-2 and input to the adder 60. The other vibrational velocity signal is converted into the signal indicating the vibrational displacement x by being integrated by the integrator 80, and is then subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60.

The signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33 is amplified by the amplifier 50-3 to an appropriate level and subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the

adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-6 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1,

this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 27 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x, the gain K_2 is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2, and the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical

compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x, the gain K_2 is replaced

by the product of K_2 and k_v, and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the eighteenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 19

Fig. 28 shows the construction of the MFB speaker system according to the nineteenth embodiment. Referring to Fig. 28, numerals 80-1 and 80-2 indicate integrators for integrating the

signal indicating the vibrational acceleration α from the amplifier 50-3 twice and generating the signal indicating the vibrational displacement x and 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x generated by the integrators 80-1 and 80-2. Numeral 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the amplifier 50-2 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational displacement detecting means 31 and the amplifier 50-1 are eliminated.

That is, in this embodiment, the vibrational velocity detecting means 32, the vibrational acceleration detecting means 33, the amplifiers 50-2, 50-3, the integrator 80-1, 80-2, the signal level adjusting means 51-1, 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 90-7.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's

possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational velocity v output from the vibrational displacement detecting means 32 and the signal indicating the vibrational acceleration α output from the vibrational velocity detecting means 33.

The signal indicating the vibrational velocity from the vibrational velocity detecting means 32 is amplified by the amplifier 50-2 to an appropriate level and subject to level conversion by the signal level adjusting means 51-2 before being input to the adder 60.

The signal indicating the vibrational acceleration α from the vibrational acceleration detecting means 33 is amplified by the amplifier 50-3 to an appropriate level and diverged into two individual signals. One of the diverged vibrational velocity signals is subject to level adjustment by the signal level adjusting means 51-3 and input to the adder 60. The other vibrational acceleration signal is converted into the signal indicating the vibrational displacement by being integrated twice by the integrators 80-1 and 80-2, and is subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-7 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the

vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 28 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_3 and k_x, the gain K_2 is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. The negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2. The equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are

generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_3 and k_x, the gain K_2 is replaced by the product of K_2 and k_v, and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the nineteenth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal proportional to the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α obtained by differentiating the signal indicating the vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 20

Fig. 29 shows the construction of the MFB speaker system according to the twentieth embodiment. Referring to Fig. 29, numeral 70-1 indicates a differentiator for differentiating the signal indicating the vibrational displacement x from the amplifier 50-1 and generating the signal indicating the vibrational velocity v and 70-2 indicates a differentiator for further differentiating the signal indicating the vibrational velocity v from the differentiator 70-1 and generating the signal indicating the vibrational acceleration α. Numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the amplifier 50-1, 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the differentiator 70-1 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the differentiator 70-2. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational velocity detecting means 32, the vibrational acceleration detecting means 33 and the amplifiers 50-2, 50-3 are eliminated.

That is, in this embodiment, the vibrational velocity detecting means 31, the

amplifier 50-1, the differentiators 70-1, 70-2, the signal level adjusting means 51-1, 51-2, 51-3, and the adder 60 constitute a vibration information detecting means 90-8 of the speaker unit 10.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational displacement x output from the vibrational displacement detecting means 31.

The signal indicating the vibrational displacement x is then amplified by the amplifier 50-1 to an appropriate level and diverged into two individual signals. One of the diverged vibrational displacement signals is subject to level adjustment by the signal level adjusting means 51-1 and input to the adder 60. The other vibrational displacement signal is converted into the signal indicating the vibrational velocity v by the differentiator 70-1. The signal from the differentiator 70-1 is further diverged into two individual signals so that one of the diverged signals is subject to level adjustment by the

signal level adjusting means 51-2 before being input to the adder 60. The other vibrational velocity signal is converted into the signal indicating vibrational acceleration α by being further differentiated by the differentiator 70-2 and is subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-8 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to

an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 29 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of k_1 and k_v and the gain K_3 is replaced by the product of k_1 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1.

Consequentially, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2, and the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance v is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency

f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of k_1 and k_x, the gain K_2 is replaced by the product of k_1 and k_v, and the gain K_3 is replaced by the product of k_1 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the twentieth embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v obtained by differentiating the signal indicating the vibrational displacement x and the signal indicating the vibrational

acceleration α is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 21

Fig. 30 shows the construction of the MFB speaker system according to the twenty-first embodiment.

Referring to Fig. 30, numeral 70 indicates a differentiator for differentiating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal indicating the vibrational acceleration α and 80 indicates an integrator for integrating the signal indicating the vibrational velocity v from the amplifier 50-2 and generating the signal indicating the vibrational displacement x. Numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement x from the integrator 80, 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the amplifier 50-2 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal

indicating the vibrational acceleration α from the differentiator 70. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational displacement detecting means 31, the vibrational acceleration detecting means 33 and the amplifiers 50-1, 50-3 are eliminated.

That is, in this embodiment, the vibrational velocity detecting means 32, the amplifier 50-2, the differentiator 70, the integrator 80, the signal level adjusting means 51-1, 51-2, 51-3 and the adder 60 constitute a vibration information detecting means 90-9.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational velocity v output from the vibrational velocity detecting means 32.

The signal indicating the vibrational velocity v is then amplified by the amplifier 50-2 to an appropriate level and diverged into three individual signals. The first of the diverged vibrational displacement signals is subject to

level adjustment by the signal level adjusting means 51-2 and input to the adder 60. The second vibrational velocity signal is converted into the signal indicating the vibrational displacement x by being integrated by the integrator 80, subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60. The third vibrational velocity signal is converted into the signal indicating the vibrational acceleration α by being differentiated by the differentiator 70, subject to level adjustment by the signal level adjusting means 51-3 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-9 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up

so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 30 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x, the gain K_2 is replaced by the product of K_2 and k_v and the gain K_3 is replaced by the product of K_2 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1 and the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2. Consequently, the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical

compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_2 and k_x, the gain K_2 is replaced by the product of K_2 and k_v, and the gain K_3 is replaced by the product of K_2 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the twenty-first embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal

composed of the signal indicating the vibrational displacement x obtained by integrating the signal indicating the vibrational velocity v, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α obtained by differentiating the signal indicating the vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

Embodiment 22

Fig. 31 shows the construction of the MFB speaker system according to the twenty-second embodiment. Referring to Fig. 31, numeral 80-1 indicates an integrator for integrating the signal indicating the vibrational acceleration α from the amplifier 50-3 and generating the signal indicating the vibrational velocity v and 80-2 indicates an integrator for further integrating the signal indicating the vibrational velocity v from the integrator 80-1 and generating the signal indicating the vibrational displacement x. Numeral 51-1 indicates a signal level adjusting means with a gain k_x for adjusting the level of the signal indicating the vibrational displacement

x from the integrator 80-2, 51-2 indicates a signal level adjusting means with a gain k_v for adjusting the level of the signal indicating the vibrational velocity v from the integrator 80-1 and 51-3 indicates a signal level adjusting means with a gain $k\alpha$ for adjusting the level of the signal indicating the vibrational acceleration α from the amplifier 50-3. The other aspects of the construction are identical to those shown in Fig. 21 of the thirteenth embodiment except that the vibrational displacement detecting means 31, the vibrational velocity detecting means 32 and the amplifiers 50-1, 50-2 are eliminated.

A description will now be given of the operation.

For example, when an acoustic signal amplified using the power amplifier in the user's possession is input directly, via the input terminal 100, to the first voice coil 10-1 of the speaker unit 10 with the input voltage E_1, the diaphragm of the speaker unit 10 vibrates. The vibrational information available in this construction includes the signal indicating the vibrational acceleration α output from the vibrational velocity detecting means 33.

The signal indicating the vibrational acceleration α is amplified by the amplifier 50-3 to an appropriate level and diverged into two individual signals. One of the diverged vibrational acceleration signals is subject to

level adjustment by the signal level adjusting means 51-3 before being input to the adder 60. The diverged vibrational acceleration signal is converted into the signal indicating the vibrational velocity v by being integrated by the integrator 80-1. The signal from the integrator 80-1 is further diverged into two individual signals. One of the vibrational velocity signals from the integrator 80-1 is subject to level adjustment by the signal level adjusting means 51-2 before being input to the adder 60. The other vibrational velocity signal from the integrator 80-1 is converted into the signal indicating the vibrational displacement x by being further integrated by the integrator 80-2 and is subject to level adjustment by the signal level adjusting means 51-1 before being input to the adder 60.

The signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α are added by the adder 60 and output therefrom. That is, the signal proportional to the vibrational displacement x, the signal proportional to the vibrational velocity v and the signal proportional to the vibrational acceleration α are added and output from the vibration information detecting means 90-9 as a sum signal. After being amplified by the power amplifier 40, the sum signal is supplied to the second voice coil 10-2 with a

positive or negative polarity with respect to the first voice coil 10-1.

When the signal is supplied with a positive polarity, a positive feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2. From the perspective of the first voice coil 10-1, this is equivalent to an increase of the equivalent mechanical compliance and a decrease of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

When the signal is supplied with a negative polarity, a negative feedback is set up so that the input voltage E_2 proportional to the vibrational displacement x, vibrational velocity v and vibrational acceleration α is supplied to the second voice coil 10-2 with a negative polarity. From the perspective of the first voice coil 10-1, this is equivalent to a decrease of the equivalent compliance and an increase of the equivalent mechanical resistance and equivalent mechanical mass in the mechanical equivalent circuit of the entire system.

The mechanical equivalent circuit of the MFB speaker system of Fig. 31 and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is

replaced by the product of K_3 and k_x, the gain K_2 is replaced by the product of K_3 and k_v and the gain K_3 is replaced by the product of K_3 and $k\alpha$ in Fig. 22.

The negative equivalent mechanical compliance C_{NG} changes with a change in the amplifier 50-1 for amplifying the signal indicating the vibrational displacement x and in the signal level adjusting means 51-1. Consequently, the negative equivalent mechanical resistance R_{NG} changes with a change in the amplifier 50-2 for amplifying the signal indicating the vibrational velocity v and in the signal level adjusting means 51-2 and the equivalent mechanical mass M_{NG} changes with a change in the amplifier 50-3 for amplifying the signal indicating the vibrational acceleration α and in the signal level adjusting means 51-3.

That is, when the gain is adjusted so as to increase the feedback to the second voice coil 10-2, the negative equivalent mechanical compliance C_{NG} is decreased, as demonstrated by the expression (6), and the negative mechanical resistance R_{NG} and the negative equivalent mechanical mass M_{NG} are increased, as demonstrated by the expression's (7) and (8) above. Consequently, the equivalent mechanical compliance is increased, and the equivalent mechanical resistance and equivalent mechanical mass are decreased from the perspective of the entire

speaker system. When the positive feedback is used, the feedback rate is adjusted in the mechanical equivalent circuit shown in Fig. 22 so that none of the entire equivalent mechanical compliance, equivalent mechanical resistance and equivalent mechanical mass becomes negative, thus preventing oscillation of the MFB speaker system.

If the feedback to the second voice coil 10-2 is increased, the lowest resonance frequency f_0 drops assuming that the equivalent mechanical mass M_0 remains constant, as in the thirteenth embodiment. Q_0 varies with the feedback rate of the signal indicating the vibrational displacement x, the signal indicating the vibrational velocity v and the signal indicating the vibrational acceleration α.

In the negative feedback, the mechanical equivalent circuit and the operation thereof are generally the same as disclosed in Fig. 22 except that the gain k_1 of the amplifier is replaced by the product of K_3 and k_x, the gain K_2 is replaced by the product of K_3 and k_v, and the gain K_3 is replaced by the product of K_3 and $k\alpha$. In the negative feedback, the negative equivalent mechanical compliance C_{NG}, the negative equivalent mechanical resistance R_{NG} and the negative mechanical mass M_{NG} change to a positive value, and the speaker system operates as a combination of the related-art displacement MFB system, velocity MFB system and acceleration MFB system.

Thus, according to the twenty-second embodiment, the speaker unit 10 of the double voice coil type having the first and second voice coils 10-1 and 10-2 is used, the sum signal composed of the signal indicating the vibrational displacement x obtained by integrating the signal indicating the vibrational acceleration α twice, the signal indicating the vibrational velocity v obtained by integrating the signal indicating the vibrational acceleration α, and the signal indicating the vibrational acceleration α obtained by differentiating the signal indicating the vibrational velocity v is amplified by the power amplifier 40 and is input to the second voice coil 10-2, while the acoustic signal is amplified by an external power amplifier and input directly to the first voice coil 10-1. Therefore, the user can use a power amplifier in his or her possession or use an amplifier of his or her own choice.

The present invention is not limited to the above-described embodiments, and variations and modifications may be made without departing from the scope of the present invention.

CLAIMS:

1. A MFB speaker system comprising:

a speaker unit (10) provided with a first voice coil (10-1) for inputting an external acoustic signal and a second voice coil (10-2) for inputting vibrational information obtained by outputting the acoustic signal;

vibrational information detecting means (91) for detecting the vibrational information of said speaker unit; and

amplifying means (40) for amplifying the vibrational information detected by said vibrational information detecting means and feeding back the vibrational information to the second voice coil with one of a positive and negative polarity with respect to the external acoustic signal.

2. The MFB speaker system according to claim 1, characterized in that

the vibrational information of the speaker unit is a signal proportional to a vibrational velocity of a diaphragm of said

speaker unit.

3. The MFB speaker system according to claim 1, characterized in that

the vibrational information of the speaker unit is a signal proportional to a vibrational acceleration of a diaphragm of said speaker unit.

4. The MFB speaker system according to claim 1, characterized in that

the vibrational information of the speaker unit is a signal proportional to a vibrational displacement of a diaphragm of said speaker unit.

5. The MFB speaker system according to claim 1, characterized in that

said amplifying means (51, 40) at least includes an amplifier (51) for amplifying only the vibrational information of the speaker unit.

6. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of said speaker unit and a signal proportional to a vibrational velocity of the diaphragm.

7. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of said speaker unit and generates a signal proportional to a vibrational velocity of the diaphragm by differentiating the signal proportional to the vibrational displacement; and

said amplifying means amplifies the signal proportional to the vibrational displacement and the signal proportional to the vibrational velocity and feeds back the signals to the second voice coil.

8. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of said speaker unit and generates a signal proportional to a vibrational displacement of the diaphragm by integrating the signal proportional to the vibrational velocity; and

said amplifying means amplifies the signal proportional to the vibrational displacement and the signal proportional to the vibrational velocity and feeds back the signals to the second voice coil.

9. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of said speaker unit and a signal proportional to a vibrational acceleration of the diaphragm.

10. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational displacement of a diaphragm of said speaker unit and generates a signal proportional to a vibrational acceleration of the diaphragm by differentiating the signal proportional to the vibrational displacement; and

said amplifying means amplifies the signal proportional to the vibrational displacement and the signal proportional to the vibrational acceleration and feeds back the signals to the second voice coil.

11. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational acceleration of a diaphragm of said speaker unit and generates a signal proportional to a vibrational displacement of the diaphragm by integrating the signal proportional to the vibrational acceleration; and

said amplifying means amplifies the

signal proportional to the vibrational displacement and the signal proportional to the vibrational acceleration and feeds back the signals to the second voice coil.

12. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of said speaker unit and a signal proportional to a vibrational acceleration of the diaphragm.

13. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational velocity of a diaphragm of said speaker unit and generates a signal proportional to a vibrational acceleration of the diaphragm by differentiating the signal proportional to the vibrational velocity; and

said amplifying means amplifies the

signal proportional to the vibrational velocity and the signal proportional to the vibrational acceleration and feeds back the signals to the second voice coil.

14. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means retrieves, as the vibrational information, a signal proportional to a vibrational acceleration of a diaphragm of said speaker unit and generates a signal proportional to a vibrational velocity of the diaphragm by integrating the signal proportional to the vibrational acceleration; and

said amplifying means amplifies the signal proportional to the vibrational velocity and the signal proportional to the vibrational acceleration and feeds back the signals to the second voice coil.

15. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a

vibrational displacement, vibrational velocity and vibrational acceleration of a diaphragm of said speaker unit, so as to output a sum signal obtained by adding a signal indicating the vibrational displacement, a signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

16. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational displacement and vibrational acceleration of a diaphragm of said speaker unit and generates a signal indicating a vibrational velocity by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

17. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational displacement and vibrational acceleration of a diaphragm of said speaker unit and generates a signal indicating a vibrational velocity by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating a vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

18. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational displacement and vibrational velocity of a diaphragm of said speaker unit and generates a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational velocity so as to output a sum signal obtained by adding the signal indicating a vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

19. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational displacement and vibrational velocity of a diaphragm of said speaker unit and generates a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, a signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

20. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational velocity and vibrational acceleration of a diaphragm of said speaker unit and generates a signal indicating a vibrational displacement by integrating a signal indicating the vibrational velocity so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

21. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational velocity and vibrational acceleration of a diaphragm of said speaker unit and generates a signal indicating a vibrational displacement by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, a signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

22. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational displacement of a diaphragm of said speaker unit and generates a signal indicating a vibrational velocity and a signal indicating a vibrational acceleration by integrating a signal indicating the vibrational displacement so as to

output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

23. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting means detects, as the vibrational information, a vibrational velocity of a diaphragm of said speaker unit, generates a signal indicating a vibrational displacement by integrating a signal indicating the vibrational velocity and generates a signal indicating a vibrational acceleration by differentiating a signal indicating the vibrational displacement so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and the signal indicating the vibrational acceleration.

24. The MFB speaker system according to claim 1, characterized in that

said vibrational information detecting

means detects, as the vibrational information, a vibrational acceleration of a diaphragm of said speaker unit and generates a signal indicating a vibrational displacement and a signal indicating a vibrational velocity by integrating a signal indicating the vibrational acceleration so as to output a sum signal obtained by adding the signal indicating the vibrational displacement, the signal indicating the vibrational velocity and a signal indicating the vibrational acceleration.

25. The MFB speaker system according to claim 1, characterized in that

said vibration information detecting means adjusts the level of a signal indicating the vibrational displacement.

26. The MFB speaker system according to claim 1, characterized in that

said vibration information detecting means adjusts the level of a signal indicating the vibrational velocity.

27. The MFB speaker system according to claim 1, characterized in that

said vibration information detecting means adjusts the level of a signal indicating the vibrational acceleration.

28. A MFB speaker system as herein described with reference to Figures 3 to 31 of the accompanying drawings.

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Claims searched: 1 to 27

Examiner: Peter Easterfield
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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H4J (JGC)

Int Cl (Ed.6): H04R 3/00

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2010639 A (MATSUSHITA)	
A	GB 1348643 A (EMI)	
X	DE 2629605 A1 (BRAUN)	1 at least
A	EP 0150976 A2 (ARNTSON et al)	

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